VOLUME 84 NO. PL2

JUNE 1958

PART 1

JOURNAL of the

Pipeline Division

PROCEEDINGS OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

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This Journal represents an effort by the Society to deliver information to the reader with the greatest possible speed. To this end the material herein has none of the usual editing required in more formal publications.

Original papers and discussions of current papers should be submitted to the Manager of Technical Publications, ASCE. The final date on which a discussion should reach the Society is given as a footnote with each paper. Those who are planning to submit material will expedite the review and publication procedures by complying with the following basic requirements:

1. Titles should have a length not exceeding 50 characters and spaces.

2. A 50-word summary should accompany the paper.

3. The manuscript (a ribbon copy and two copies) should be double-spaced on one side of 8½-in. by 11-in. paper. Papers that were originally prepared for oral presentation must be rewritten into the third person before being submitted.

4. The author's full name, Society membership grade, and footnote reference stating present employment should appear on the first page of the paper.

5. Mathematics are reproduced directly from the copy that is submitted. Because of this, it is necessary that capital letters be drawn, in black ink, ⅛-in. high (with all other symbols and characters in the proportions dictated by standard drafting practice) and that no line of mathematics be longer than 6½-in. Ribbon copies of typed equations may be used but they will be proportionately smaller in the printed version.

6. Tables should be typed (ribbon copies) on one side of 8½-in. by 11-in. paper within a 6½-in. by 10½-in. invisible frame. Small tables should be grouped within this frame. Specific reference and explanation should be made in the text for each table.

7. Illustrations should be drawn in black ink on one side of 8½-in. by 11-in. paper within an invisible frame that measures 6½-in. by 10½-in.; the caption should also be included within the frame. Because illustrations will be reduced to 69% of the original size, the capital letters should be ⅛-in. high. Photographs should be submitted as glossy prints in a size that is less than 6½-in. by 10½-in. Explanations and descriptions should be made within the text for each illustration.

8. Papers should average about 12,000 words in length and should be no longer than 18,000 words. As an approximation, each full page of typed text, table, or illustration is the equivalent of 300 words.

Further information concerning the preparation of technical papers is contained in the "Technical Publications Handbook" which can be obtained from the Society.

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AT,BD,CP,CO,HW,IR,SU,WW,PL.

Journal of the

PIPELINE DIVISION

Proceedings of the American Society of Civil Engineers

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June, 1958

Papers

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PIPELINE DIVISION

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HIGHWAY ENGINEERS AND PIPELINERS CAN SOLVE MUTUAL PROBLEMS[a]

C. D. Richardson[1]

The ever-increasing population and expanding economy of our country continually generate a need for better transportation. The increased tempo of the rise in our standard of living has magnified the demand for better and more convenient home appliances, and bigger, faster and more comfortable automobiles for family and business use.

We demand quick, efficient, dependable service compatible with our spiraling standard of living. The millions of high-speed cars and trucks need well-designed and constructed highways to provide comfortable and safe travel.

Our people also demand a supply of better, more convenient, and cheaper fuel. Today there are pipelines carrying oil or gas to every state in our union. Thousands of miles of new pipelines are planned for construction this year, next year, and on into the future in order that more and more homes can enjoy the convenience of an economical fuel. Below are statistics showing how U. S. pipeline mileage will grow during 1958.

	Miles in Ground Through 1956	Miles Laid in 1957	Miles Forecast for 1958
Gas			
Transmission	152,490	7,260	10,367
Gathering	47,370	2,439	3,401
Total Transmission & Gathering Lines	199,860	9,699	13,768
Crude Oil			
Trunk		2,157	1,795
Gathering		1,417	1,395
Total Crude Lines		3,574	3,190
Products			
All Lines		2,035	1,344
Year's Total		15,308	18,302

Note: Discussion open until November 1, 1958. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1666 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 2, June, 1958.

a. Presented before a Joint Session of Pipeline, Highway, and Surveying & Mapping Divisions, American Society of Civil Engineers, Chicago, Ill., February 24, 1958.

1. Asst. Supt. of Pipelines, Transcontinental Gas Pipe Line Corp., Houston, Tex.

The statistics bear out the fact that the gas pipeline industry is still increasing its rate of expansion. With nearly 200,000 miles of gas pipeline in the ground in 1956, the 9,699 miles of pipe laid in 1957 represented a percentage increase in total mileage of approximately 4.9%. The forecast of 13,768 miles of gas pipeline for installation in 1958 represents a percentage increase of approximately 6.6% of all pipe mileage in the ground through 1957.

Nearly everyone is familiar with the term "highway" and the purpose of a highway. However, the term "pipeline" may not be as well understood, as it is, in its modern conception, part of a new terminology in a relatively new industry. Pipeliners understand "pipeline" as a term describing a cross-country welded steel pipe transporting crude oil, natural gas, or petroleum products. The general principles and many of the problems encountered are common to the construction of the highway.

The Civil Engineer is recognized as being particularly fitted to carry out important work in all phases of pipeline construction from inception to operation. Through this interest a pipeline committee was created within the construction division of the American Society of Civil Engineers in 1953. In 1956 the pipeline committee became the Pipeline Division, a full-fledged division of the ASCE. Program organizers for this meeting felt that a review of the common problems of pipeline and highway engineers in highway crossings would be appropriate.

In many ways the problems experienced by State Highway Departments and all those concerned with highway construction parallel those faced by the Pipeline Industry. Both are continually striving to meet and serve the ever-expanding needs of the public.

To satisfy the requirements of the automobile age, roads have progressed from the deep-rutted buggy trails of the past to the super highways of today. In like fashion the pipeline industry has expanded in only a few decades from short, low-pressure, small-diameter cast-iron pipelines to large-diameter, high-pressure, welded-steel pipelines extending to fuel-hungry areas throughout the United States.

The enactment of the Federal Highway Act of 1956 to create an Interstate Highway System throughout the United States immediately multiplied highway problems and correspondingly multiplied pipeline problems.

Although the Interstate program is still in its infancy, one Company last year did construction work costing in excess of $100,000 in relocating, lowering and casing our pipeline facilities to accommodate new highway construction. Projects we already know of scheduled for this year will be in excess of three quarters of a million dollars.

New high-pressure gas-transmission lines are designed and installed so as to provide adequately for public safety under all conditions encountered. In carrying this out and to assure uniformity of standards, all designs and installations are in accordance with the provisions set forth in Section 8 of the American Standard Code for Pressure Piping (ASA B-31.1).

In 1951, Sectional Committee B-31 of the American Society of Mechanical Engineers authorized the establishment of the Code for Pressure Piping to provide an integrated document for construction, operation and maintenance of gas transmission and distribution piping systems.

Later, in the light of modern materials and methods of construction and operation, a new sub-committee Number 8 was appointed to take over responsibility for this section of the code. Sub-committee 8 members and representatives from transmission and distribution companies from all over

the United States worked together to create the Code that today delineates adequately safe construction and operating practices. Original design and construction in accordance with the Code present no serious problem, but to revamp an operating line to conform with Code requirements for new highway crossings gives rise to problems requiring considerable planning and expense.

In nearly all instances pipeline companies are reimbursed by the various highway departments for material and labor costs incurred in revamping pipeline facilities to accommodate highway construction. In addition, gas pipeline companies are reimbursed for gas lost when it is necessary to cut and relocate facilities. However, the sale price of gas which transmission companies are unable to deliver while their lines are out of service is never recoverable.

Still, there seems to be a marked tendency among highway engineers to disregard pipeline facilities in the design of new highways. The tendency may well be because of the lack of knowledge of the paramount rights of the pipeline right-of-way or of the tremendous cost often required in relocating an operating pipeline.

Therefore, there are three key words representing actions which will lead to mutual benefits for all.

NOTIFICATION
DISCUSSION = $SAVINGS FOR ALL CONCERNED
COOPERATION

Ample notification concerning impending projects, adequate discussion between highway and pipeline engineers, coupled with a spirit of cooperation—these three will produce dollar savings for all concerned. These dollar savings, of course, ultimately represent savings for the customer and taxpayer whose interests should be protected.

A transmission line is normally engineered with sufficient safety factor for the area covered at the time of construction with due regard for any foreseeable change. In all cases the pipeline is safe to carry the pressure for which it is designed. In areas where the pipeline might be subjected to damage from excessive loading or from external damage beyond our control, we add to the safety factor. It is really surprising how many building contractors are willing to run into a high-pressure line with excavation equipment.

Consequently, notification well in advance of construction is needed to open the door for intelligent discussion of all problems involved. With ample notification required materials can be economically purchased and necessary revamping work intelligently planned without paying crash program prices.

A new highway invariably requires either a new right-of-way or widening of the existing right-of-way. In this new right-of-way area the odds are that the pipeline will have a safety factor for cross-country piping. Probably it will also have only a minimum cover of 3 feet and will conform to the natural terrain prevailing. Consequently, grading of any amount would result in our having to lower our pipeline in place and case it or having to cut and lower it at a tremendous cost.

If a pipeline must be relocated only slightly to accommodate a new highway, the costs compared to a simple casing job usually run about 4 to 1. For example: The comparative costs for a pipeline relocation with casing a line in place might run on a cost breakdown something like this.

	Cost for Relocation	Cost for Casing in Place
Material	$ 9,200	$2,700
Labor	8,300	2,000
Equipment	2,500	1,000
Field Engineering and Supervision	1,000	400
Gas Loss	2,100	-0-
Overheads	2,900	400
Total Cost	$26,000	$6,500

It is noted that when a line can be cased in place rather than relocated, all gas loss and a great deal of material costs can be saved. Also the labor, equipment, engineering, supervision and overhead costs are reduced accordingly. Thus, it behooves the highway engineer to investigate adding to the grade across pipeline right-of-way wherever possible instead of reducing the grade.

Example #1 shows a breakdown of probable costs for a given location in casing a pipeline in place. Frequently highway authorities think the costs incurred in doing this sort of work with maintenance labor are out of line. Lower bids have been quoted by independent contractors, but they have not been accepted as applicable.

The basic factor overlooked is that working around a loaded high-pressure pipeline is a lot like carrying a basket of eggs. As long as everything is handled properly there will not be any cracked eggs—or pipelines. For example, when installing casing on a loaded line, excavation equipment can be utilized only so close to the line and then the line must be uncovered with hand tools. Instead of slipping the pipe through casing in place as in new construction, the casing must be split and welded in place over the pipeline. To allow installation of the split casing the pipe must be completely free from contact with the earth, since the casing is at least 4" larger in diameter than the pipe. With the pipe already withstanding considerable hoop stress from high-pressure gas, care must be taken to prevent the pipe from being subjected to abnormal stress from external forces. Therefore, the excavated span of the pipe between supporting earth-bearing points is limited to the minimum length required to install 30 or 40 foot lengths of casing at a time.

After the first length of casing is installed, well-tamped soil or sand is placed underneath the casing to restore as nearly as possible the original load-bearing surface. This whole process is repeated until the entire required length of casing is installed. On some occasions highway authorities have required backfilling over the casing only with a suitable sand. When backfilling with sand is required, some disposition must be made of the earth originally excavated.

In view of all of these problems, the risk included in letting "just anyone" work on a pipeline must be avoided. The company people, in working on loaded lines, have respect for the dangers involved and the know-how to carry out the work safely. On new construction, of course, such caution is not necessary, and costs will be lower.

Example #2 shows a highway right-of-way crossing a pipeline without regard to location. Although such a crossing can be cased by mitre welding, it leaves a very bad situation. If any trouble should ever develop in the pipe

underneath the road, it would be necessary to cut the road in order to remove, repair and replace the pipe. Here again, if the highway right-of-way location cannot be changed, the only alternative to casing in this fashion is to relocate the pipeline at an enormous cost.

A good demonstration of the results of lack of notification, discussion or cooperation experienced in one case is represented by Example #3.

In this particular instance it was considered desirable to move valve facilities from the middle of a cultivated field to an accessible point for a farmer's and the Company's mutual benefit. A check with the highway authorities in consideration of a possible expansion of the highway right-of-way revealed no objections to the relocation. The facilities were relocated and within one year the same highway authorities indicated that the valve settings must be moved. This, at great expense to accommodate the new highway designed as shown without regard to existing facilities.

This represents a completely unnecessary cost for all concerned.

Example #4 represents the benefits that can be derived by everyone from a true spirit of cooperation.

In this particular area a single line existed close to the market. Notification was received from state highway authorities that a relocation of facilities was necessary to allow construction of a new highway. Subsequently, in the example shown the State indicated that they would provide the required right-of-way for the relocation. At that time highway authorities were asked if the construction could be deferred to permit acceleration of construction of a second line previously planned for future construction. Thus, allowing service to be maintained next to the market area. The State agreed to study this proposal and in the meantime the program for a second line was begun. Shortly thereafter the State was bogged down in obtaining approval of the highway project and planning had almost gone too far to back down from a loop line. To complicate the matter the Company has no right to go through the new right-of-way to be procured by the State. This leaves no alternative but to follow the old right-of-way with the new line, which would require moving two lines instead of one when the highway is ultimately built. The highway authorities have been informed of these facts and now have the opportunity to step up their program and hold to the original costs instead of multiplying them by 2.

It is realized that highways cannot be designed to accommodate pipelines. However, on many occasions by moving a highway only a few hundred feet without detriment to the overall scheme, or by adding grade instead of removing it, many thousands of dollars can be saved and all concerned can be relieved of a lot of unnecessary problems.

Additionally, highway authorities could help by setting up departments to approve pipeline construction drawings as designed to accommodate highway construction. In this way assurance of meeting highway design requirements can be obtained and costly construction revisions eliminated.

If advance information is given profiles and any other information required throughout proposed highway construction areas across pipeline right-of-way can be provided. In many cases exact information in advance about the location of proposed highways would permit installation of casing during regular pipeline construction.

By conferring together mutual problems can be solved.

All of this will result in the cooperation necessary to produce a better and less expensive job for all concerned.

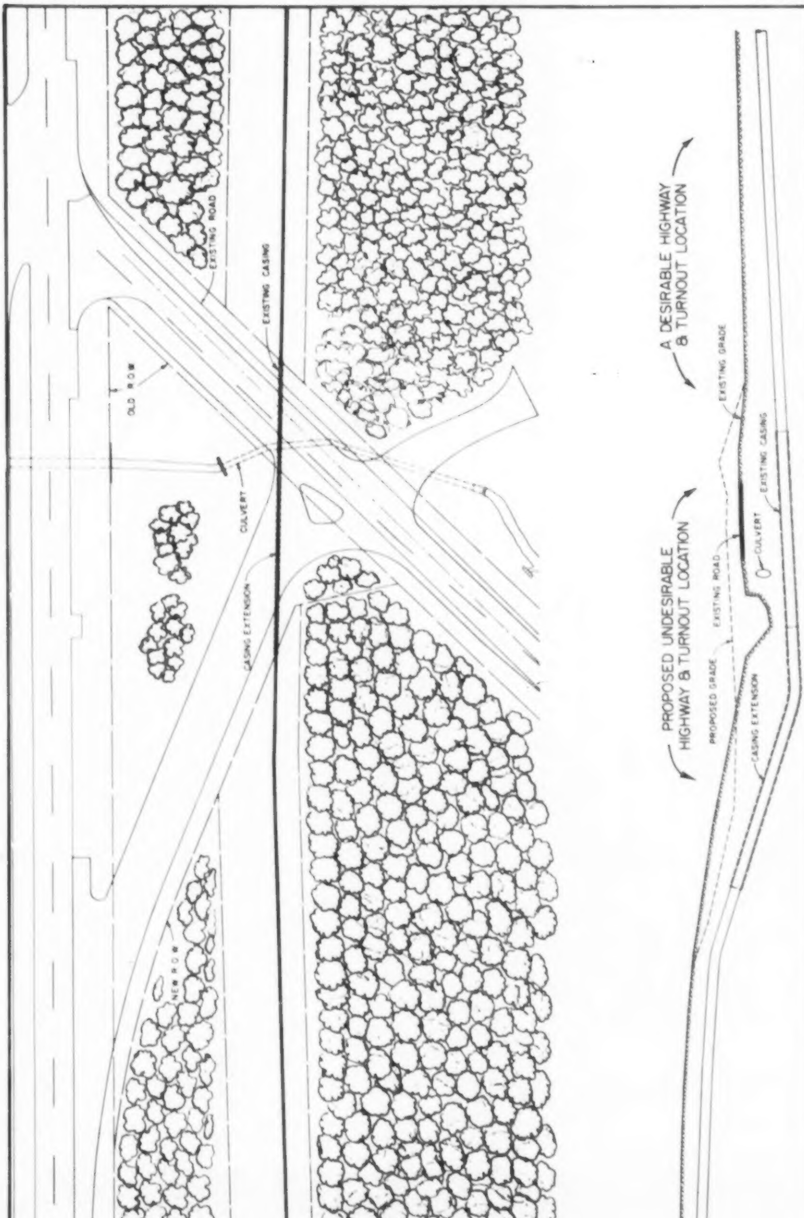
CONSTRUCTION WORK ORDER ESTIMATE

REQUEST NO.	DATE REQUESTED	BUDGET NO.	W.O. NO.	DATE ISSUED	LOCATION NO.

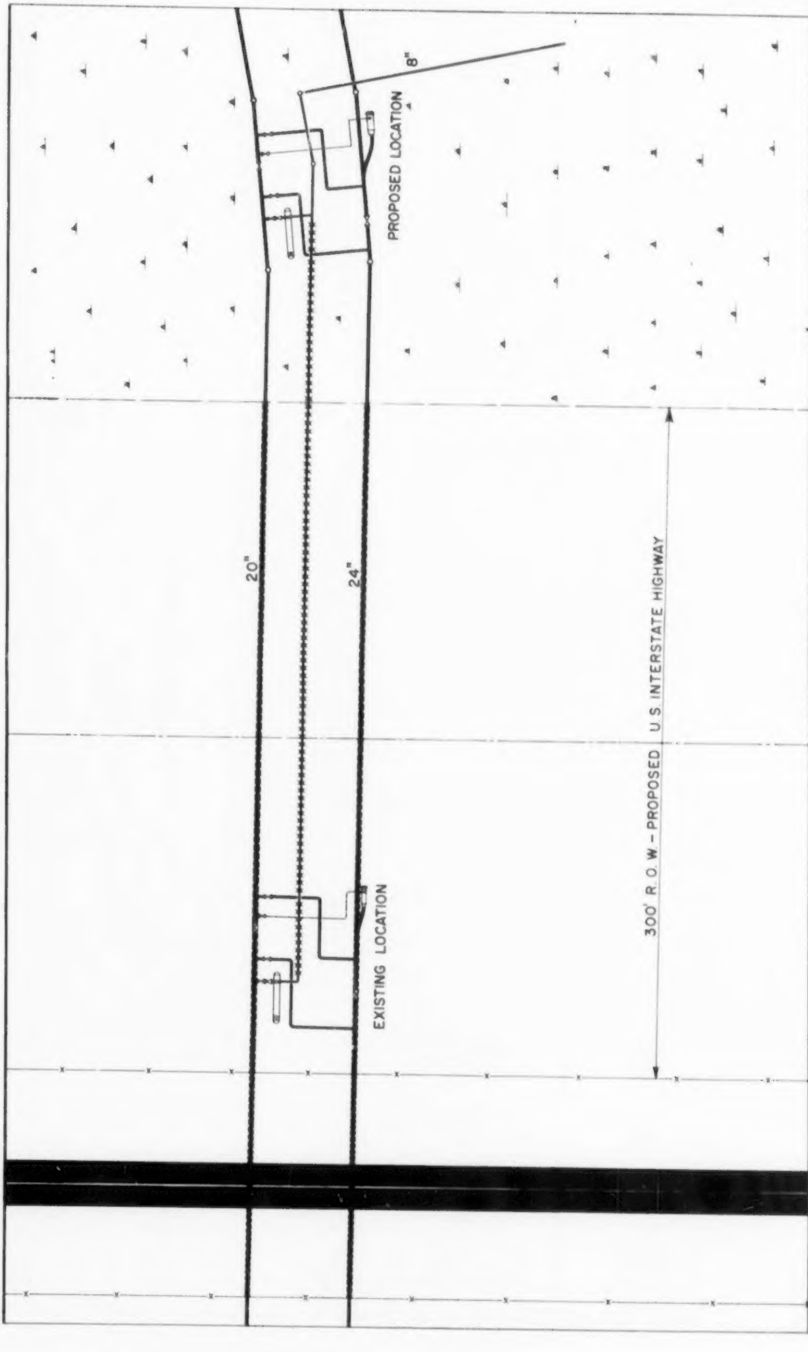
DEPARTMENT: PIPE LINE
LOCATION: Houston, Texas
DESCRIPTION OF WORK: Install 142 feet of Casing on 30" Main Line for new interstate Highway.

COST CLASS.	PARTICULARS	UNIT	QUANTITY	UNIT PRICE	ESTIMATED EXPENDITURES (X DENOTES "NON-CASH" ITEMS) MATERIAL AND EQUIPMENT	LABOR	OTHER COSTS	CONTRACT COSTS	TOTAL
30	Pipe-Valves & Fittings								
	(1) Casing-42" x .375" W.T. to be split by Field Forces	Ft.	142	15.77	2,239 x				2,239
	(2) Casing End Seals, Maloney Zipper Type	EA.	2	60.00	120				120
	(3) Casing Insulators, For Insulating on 30" O.D. Pipe & 42" O.D. x .375 W.T. Casing	Ea.	8	30.00	240				240
	(4) 2" x .154 WT 180° Return Bend	Ea.	1	4.60	5				5
	(5) Pipe, 2" x .154 WT Vent Pipe	Ft.	10	.50	5 x				5
	(6) Mile Post Marker-Edwards concrete	Ea.	1	6.00	6 x				6
	(7) Miscellaneous Material, Welding rod, acetylene, oxygen, coating material, etc.	Lot	1		100				100
	(8) Equipment Use	Lot	1				1,000		1,000
	(9) Stores Clearing		$2,250	10%			225		225
	(10) Installation of Casing-Company Labor to Split Casing-haul to Job site & Install.	Lot	1			2,575	400		2,975
	(11) Bonus, Insurance & Taxes		$ 2,575	10.2%		263			263
	Subtotal-30, Pipe, Valves & Fittings				$2,715	$2,838	$1,625		$7,178
84	Field Engineering & Supervision								
	(1) Labor & Other Costs		7,178	3%		125	90		215
	(2) Vacation & Holidays		2,700	6%		162			162
	(3) Bonus, Insurance & Taxes		125	10.2%		13			13
	Subtotal-84, Field Engineering & Supervision					$ 300	$ 90		$ 390
	Total Direct Cost				$2,715	$3,138	$1,715		$7,568
	Design, Engineering, Supervision Drafting, Purchasing, and other General Administrative Costs		$3,138	15%			$ 471		$ 471
	TOTAL ESTIMATED COST				$2,715	$3,138	$2,186		$8,039

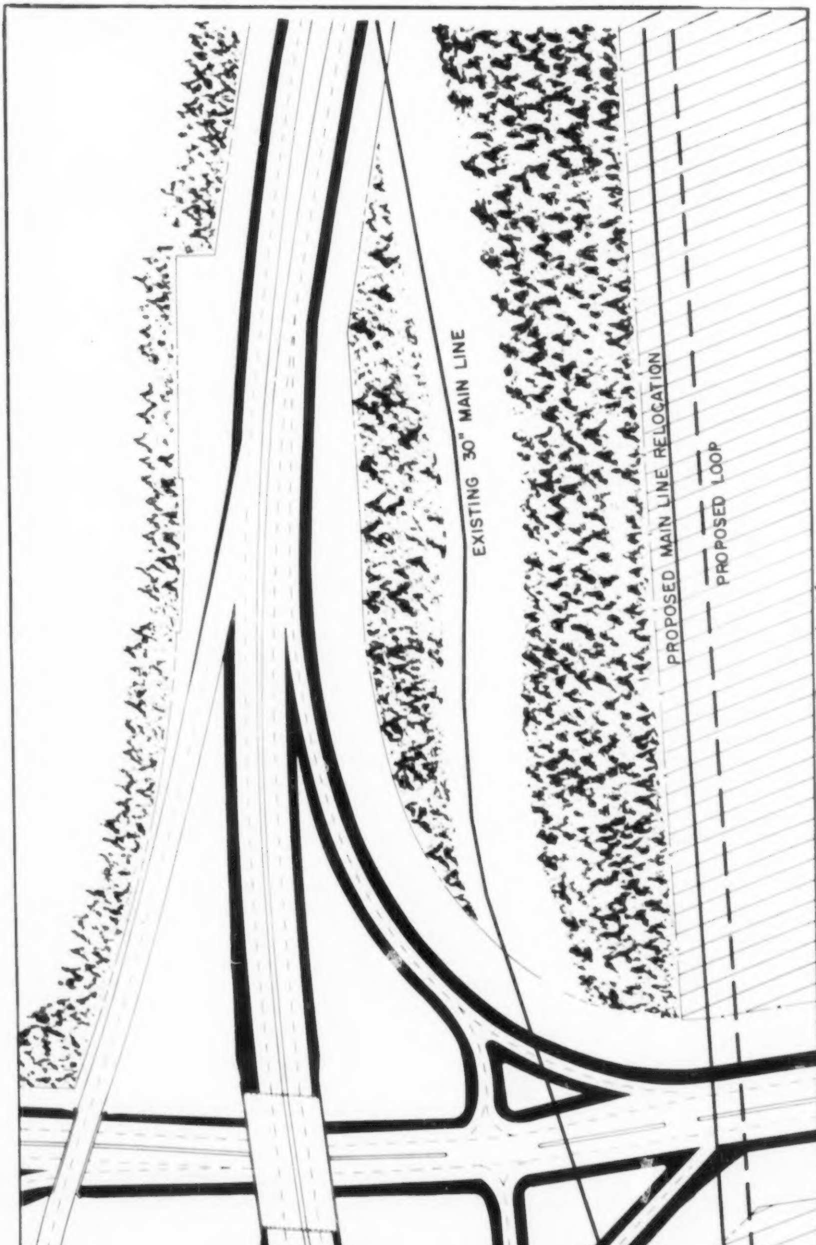
Example #1


EXISTING ROAD
EXISTING CASING
OLD R.O.W.
CULVERT
CASING EXTENSION
NEW R.O.W.
A DESIRABLE HIGHWAY & TURNOUT LOCATION
PROPOSED UNDESIRABLE HIGHWAY & TURNOUT LOCATION
EXISTING GRADE
EXISTING CASING
CULVERT
EXISTING ROAD
PROPOSED GRADE
CASING EXTENSION

Example #2


8"
PROPOSED LOCATION
20"
24"
300' R.O.W. - PROPOSED U.S. INTERSTATE HIGHWAY
EXISTING LOCATION

Example #3


EXISTING 30" MAIN LINE
PROPOSED MAIN LINE RELOCATION
PROPOSED LOOP

Example #4

Paper 1667 June, 1958 PL 2

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

FLOW EQUATIONS FOR NATURAL GAS PIPELINES[a]

R. F. Bukacek[1]
(Proc. Paper 1667)

To obtain a proper perspective on the flow equations for the natural gas transmission industry it is necessary to distinguish among their applications, which are principally three:

1. Design of pipelines for capacity
2. Pipeline operations study
3. Pipeline capacity testing

Design of Pipelines for Capacity

While the problem of designing pipelines for capacity involves a multitude of economic factors, this discussion is limited to the question of the equations which relate operating conditions and pipeline dimensions to capacity. In combination with the other factors involved, a flow equation is used to determine the diameter and wall thickness of pipe, and the spacing and horsepower requirements of compressor stations. The capacity basis for design is an estimate of future requirements and this uncertainty in design basis makes less significant the absolute accuracy of the flow equation used. In general it would be desirable that the flow equation yield somewhat conservative results so that a margin of safety in operation would be obtained.

The practice in the design of pipelines has been to make use of one of the various equations and correct its prediction at given operating conditions with an experience factor, generally called "Pipeline efficiency". The numerical value of the pipeline efficiency chosen as a design base thus depends on three factors: 1) the particular flow equation chosen, 2) the terms included in the equation (for example, the compressibility factor is often omitted), and 3) experience in applying the equation to past operations. For large diameter lines (20" diameter and above) under design conditions of high throughput, experience among the different pipeline companies has been rather consistent. The three equations most widely used for design purposes are:

Note: Discussion open until November 1, 1958. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1667 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 2, June, 1958.

a. Presented before the Pipeline Div., American Society of Civil Engineers, February 26, 1958, Chicago, Ill.

1. Instructor, Chem. Eng. Dept., Illinois Inst. of Technology, Chicago, Ill.

		Design Efficiency-%
Weymouth	$Q_b = 433.5\left(\frac{T_b}{P_b}\right) D^{8/3}\left[\frac{P_1^2 - P_2^2}{GTL}\right]^{0.5}$	110
Panhandle A	$Q_b = 435.7\left(\frac{T_b}{P_b}\right)^{1.0788} D^{2.6182}\left[\frac{P_1^2 - P_2^2}{G^{0.8539}TL}\right]^{0.5392}$	92
New Panhandle	$Q_b = 737\left(\frac{T_b}{P_b}\right)^{1.02} D^{2.53}\left[\frac{P_1^2 - P_2^2}{G^{0.961}TLZ}\right]^{0.51}$	90

Note—Weymouth and Panhandle A equations as written do not include the compressibility factor.

For purposes of design these three equations give similar results at least for certain ranges of flow rate and pipe size. Fig. 1 is a comparison of these equations with the design bases listed. A compressibility factor of 0.9 was used with the new Panhandle Equation. In this figure the flow rates given by the Panhandle A and New Panhandle equations are shown relative to those given by the Weymouth Equation.

Examination of the figure reveals that the agreement between the Weymouth and New Panhandle Equations is quite good for sizes above 20" diameter but less good at smaller diameters. The Panhandle A equation is in good agreement only over the range of flows which correspond to ordinary design conditions. In general, the three flow equations with the design bases given agree within ± 4% over the range of ordinary design flow rates for the pipe sizes larger than 20 inches. Since design flow rates are generally estimates of future requirements, there is little basis for distinguishing among the equations at higher rates of flow for the larger sizes of pipe.

Pipeline Operations Study

Pipeline flow equations are also used to study the behavior of a pipeline system under various operating conditions. Where interruptible customers are spaced along the pipeline it is desirable to determine the most economical way of curtailing these customers, given the conditions which determine pipeline drawoff by non-interruptible customers. Another example is determination of system capacity given compressor station outage or similar contingency. The equations given are probably equally good for studies of this type which are necessarily based on estimated system loads.

Pipeline Capacity Testing

Inspection of Fig. 1 shows that the equation selected for use in pipeline capacity testing has a more significant bearing on the results than it does in the case of design for capacity. This is true because pipeline throughput is not maintained at the design capacity but varies depending on the character of the system's sales. It is clear from Fig. 1 that the agreement among equations is not uniform through the range of flow rates common to pipeline operation. To illustrate, inspection of Fig. 1 shows for 30" pipe exact agreement between

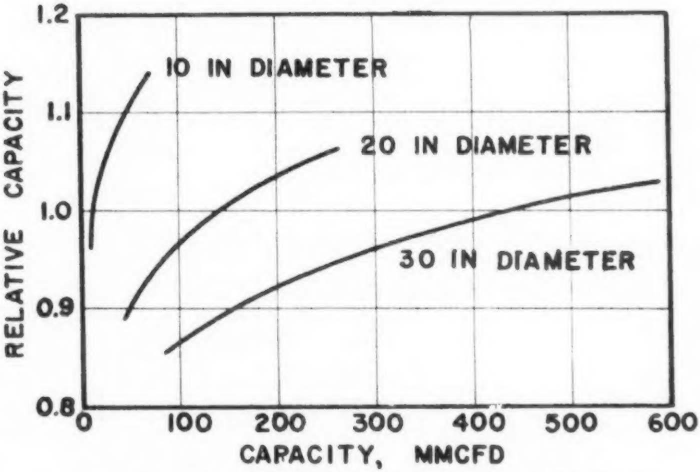


FIG I-A COMPARISON OF PANHANDLE A WITH WEYMOUTH DESIGN BASIS

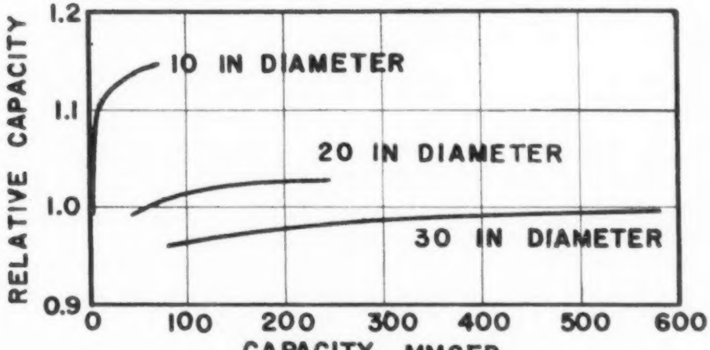


FIG I-B COMPARISON OF NEW PANHANDLE WITH WEYMOUTH DESIGN BASIS

the Panhandle A and Weymouth predictions of flow rate at 425 MMcfd, but 7.5% difference in prediction at 200 MMcfd. Assuming the Weymouth efficiency to be correct throughout the range, then the Panhandle A equation would show an efficiency at 200 MMcfd of about 100% rather than the 92% used as basis for design. In the practical order this means that the significance of efficiency test results depends on the flow equation used, and a change in efficiency may be due to the flow equation used rather than a change in pipe conditions.

Fig. 1 also shows that the different equations are inconsistent in regard to the effect of pipeline diameter. In particular, the agreement among the equations is much less marked for small diameter lines than for larger sizes. Thus the meaning of efficiency test results is dependent on pipe diameter as well as flow rate and the equation used.

The Flow Equations and the Resistance Coefficient

To clarify the differences between flow equations, it is necessary to consider that all these equations arise from consideration of the balance of energy across a pipeline section operating at steady state condition. This balance may be written in differential form as follows:

$$dE + d(PV) + \frac{dv^2}{2g_c} + \frac{g}{g_c}\,dh = q - W_s \tag{1}$$

E is the internal energy per pound of fluid.

PV is the product of pressure and specific volume. The differential represents the net work involved in forcing a pound of fluid into and out of the incremental pipeline section considered.

$\frac{v^2}{2g_c}$ is the kinetic energy per pound of fluid.

h is the elevation of the gas stream above some reference plane.

q is the heat transferred per unit mass of the gas.

W_s is the shaft work done by the gas on the surroundings in passing through the incremental section considered.

It can be shown that the change in kinetic energy is negligible under the operating conditions of natural gas pipelines. Additionally, it is convenient to consider W_s and dh to be zero, that is, that the pipeline is horizontal and that no shaft work is done on or by the gas in passing through the section. The resulting equation:

$$dE + d(PV) = q \tag{2}$$

is correct within the limitations imposed above, but yields no information about the effect of line length or pipe diameter on pressure drop. To obtain such a relationship it is necessary to introduce additional ideas. The concepts of friction and resistance coefficient will suffice. If friction is considered a form of energy transformation corresponding to the non-ideal behavior of the system, we can conveniently write

$$dE = q - PdV + F \tag{3}$$

where F represents an energy transformation not accounted for in the heat transfer or PdV term. Combining Eqs. (3) and (2):

$$VdP + F = 0 \tag{4}$$

Having introduced the concept of friction, its correlation with the variables of line length and diameter must be considered. This could be done in various ways, but it is conventionally done through the resistance coefficient as follows:

$$F = 4f\left(\frac{v^2}{2g_c}\right)\frac{dL}{D} \tag{5}$$

This form is the simplest way to introduce the variables of flow rate, length and diameter in a dimensionally consistent way. Combining Eqs. (4) and (5) we have that equation which when integrated is the ordinary flow equation. The problem of determining the values to be assigned to the resistance coefficient remains to be resolved.

From the definition, there is no obvious way to determine the behavior of the resistance coefficient except the analysis of experimental data. Dimensional analysis shows that the Reynolds number may be a correlating parameter, but does not tell what relationship between resistance coefficient and Reynolds number exists. Similarly, if it is supposed that conduit surface characteristics may be important, the dimensionless group k/D may be a correlating parameter where k is the effective height of surface irregularities. There is, however, no escape from an experimental study of the resistance coefficient.

The problem has long been studied and currently there are recognized three stable types of behavior for the resistance coefficient, and two regions of transition which lie between the patterns for stable behavior. At small values of the Reynolds number (below about 2000) a type of flow called "streamline" is found where $f = 16/Re$. As Reynolds numbers increase above 2000 a transition region is encountered which is followed by a stable regime where resistance coefficients can be approximated by the form $f = aRe^b$. This is the region where turbulent conditions exist in the vicinity of the center of the pipeline but a condition of "streamline" flow persists near the conduit walls. In this region the flow pattern is equivalent to that in perfectly smooth pipes. The thickness of this boundary layer in streamline flow decreases as Reynolds number increases until turbulence introduced at the irregularities on the conduit surface render impossible its further existence. At the state of complete turbulence the resistance coefficient no longer depends on Reynolds number.

The transition between "smooth pipe" behavior and complete turbulence depends on conduit surface roughness in a complex way. The beginning of the transition occurs when the fluid velocity at the largest roughness elements induces appreciable turbulence over and above that already developed in the turbulent core. The further development of additional turbulence depends on the size, shape and placement of the surface roughness elements. It follows that this transition region will not be the same for different conduit surfaces,

and no two commercial pipes can be expected to have the same transition behavior. This is demonstrated in Fig. 2, taken from the report of Smith et al.[2]

These types of resistance coefficient behavior have been established by the work of many investigators. Outstanding among them is Nikuradse whose experimental work on pipes coated with uniformly sized sand grains first convincingly demonstrated the existence of the region controlled by surface conditions. Nikuradse's work has been recently confirmed by Smith[2] et al whose experimental data on commercial pipe in the size range from 2 to 8 inch diameter has extended the range of Reynolds number investigated to 11×10^6. The most recent investigation covering large diameter natural gas pipelines, soon to be published by the Institute of Gas Technology, also confirms the basic pattern of resistance coefficient behaviour outlined above.

Natural Gas Pipelines and the Resistance Coefficient

Taking for granted the accuracy of the above description of resistance coefficient behavior, it remains to put these facts in the perspective of natural gas pipeline problems. The first important observation is that the viscosity of natural gases is very small, with the result that the Reynolds numbers characteristic of natural gas pipeline operation are very large. It is virtually impossible to imagine a practical natural gas pipeline operation where streamline flow might be involved. The Reynolds numbers are so large, in fact, that for high pressure pipelines above 10 inch diameter only the very small flow rates even approach the region where resistance coefficients depends on Reynolds number. For example, in order to achieve a Reynolds number of a million in a 12 inch line, the flow rate must be 10 MMcfd which is a rather low rate for this size line in high pressure natural gas service. For a 30 inch line, the flow rate to achieve a Reynolds number of 1 million is 26 MMcfd which is very small for this size of line. It follows that those flow equations which are based on an expression for resistance coefficient showing little or no dependence on Reynolds number correspond to the facts of life for large diameter high pressure natural gas pipelines.

The coefficient used in the Weymouth equation is: $f = 0.008/D^{1/3}$. In that this expression shows no dependence on Reynolds number it agrees with the findings of Nikuradse and Smith for the range of large Reynolds numbers. The Panhandle A equation is based on a friction factor of the form $f = aRe^b$, and reference to Fig. 1 shows that this leads to substantial deviations from the realities of pipeline operation. The new Panhandle equation is also based on the form $f = aRe^b$, and inspection of Fig. 1 shows that the dependence of f on Reynolds number for the larger sizes of pipe is very small in the ordinary range of flow rates. To rephrase the above observations: it would be expected that pipeline efficiencies based on Weymouth or New Panhandle Equations would be little dependent on the rate of flow chosen for test, while efficiencies determined from the Panhandle A Equation would decrease with increasing flow rate. Again, considering the range of flow rates corresponding to commercial operation of large diameter high pressure pipelines, the use of the Weymouth or New Panhandle Equations will be more consistent with the known behavior of pipelines than will the use of the Panhandle A equation.

The second point of perspective lies in consideration of the fact that in the range of flow rates common to large diameter high pressure pipelines, the

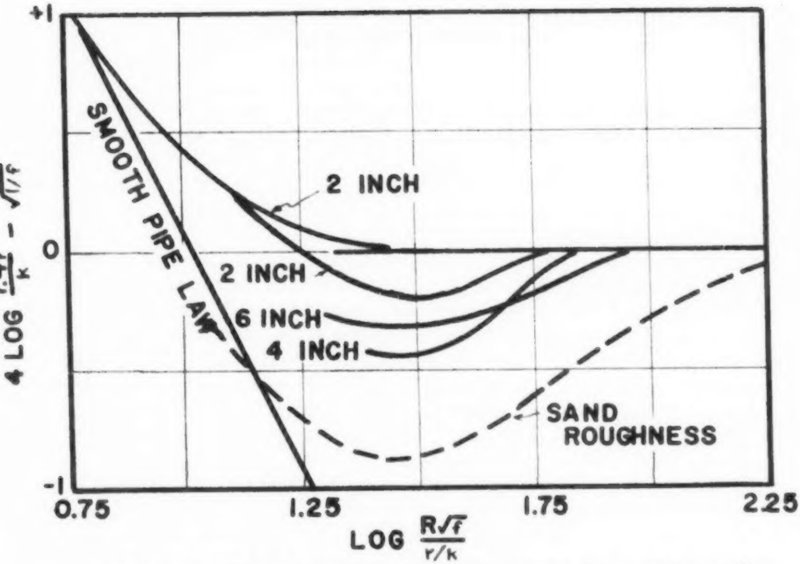


FIG 2 TRANSITION REGION, AFTER SMITH[2]

resistance coefficient is controlled by conduit surface conditions. Obviously, pipeline interior surfaces are not uniform; they depend upon the extent of corrosion, the method of pipe manufacture, and the accumulation of foreign materials (both solid and liquid) on the surfaces. It is thus clear that the resistance coefficient which characterizes a section of pipeline can change with time. Immediately following construction, pipe surface condition will depend on such factors as the length of pipe storage time above the ditch and the extent to which construction dirt has been removed. Once in operation the surface condition will be modified by factors such as the water and hydrocarbon wetness of the gas, and the possibility of processing fluids and solids being dumped into the gas. It follows that each pipeline section has its own peculiar surface condition which has been determined by its past history. It is beyond the realm of reasonable possibility that any flow equation can be devised which will contain the variables necessary to describe the effect on resistance coefficient of pipe section past history. What can be devised is, at best, a flow equation which takes into account the fact of surface control over friction factor and contains an experience factor, or efficiency which is not a function of pipe diameter and which is rational at least to the extent that it serves to distinguish between clean, commercially smooth pipelines and those not so clean and smooth.

Fortunately, the internal surface of natural gas pipelines are not so variable as they might be. Current pipe manufacturing methods do not result in grossly different base metal surfaces. Pipe cleaning practices following construction are fairly standard, and practices in connection with gas conditioning are rather uniform. Interior corrosion once the pipe is in the ground is not generally a problem. The net result is that in practice pipe wall conditions vary only narrowly except where the possibilities of accidental dumping of processing fluids and solids are frequent. This means that there is a practical upper limit to the degree of smoothness possible in a pipeline, and an effective roughness which characterizes the general run of pipelines but is not too greatly different from the practical extremes of commercial smoothness and roughness. This is shown by the data cited by Smith, et. al.,[2] who recommended for the range of large Reynolds number the Nikuradse Rough Pipe Law ($\sqrt{\frac{1}{f}} = 4 \log \frac{3.7D}{k}$) with the value $k = 0.0007$ to represent the "average" pipeline surface condition. It is also confirmed by the data of Ivey and Dorough[1] obtained on Southern Natural Gas Company's system. It should, therefore, be possible to devise an equation characterizing the commercially "smoothest" pipe to which an efficiency (or experience factor) with a value approaching unity can be applied for particular pipelines or for design purposes.

CONCLUSION

In some applications, the data required for use of the flow equations are sufficiently inexact that there is no real basis for distinguishing among the usual flow equations on the basis of their accuracy. This is not the case for pipeline capacity test data, and since the different equations do not agree on the effect of flow rate or pipe diameter on pressure drop, the equations are not equally good. Consideration of the available data on resistance coefficients, and the conditions of natural gas pipeline operations leads to the

conclusion that an equation of the "Weymouth" type is most satisfactory for large diameter lines. Because resistance coefficients for pipeline operating conditions are fixed by the internal surface of the pipe, no two pipe sections will be exactly the same, although it is to be expected that in natural gas service they will not vary too widely. While it may be possible to develop a flow equation with somewhat better properties than those currently available, it will always be necessary to use an efficiency or experience factor to account for the unpredictability of pipe surface condition.

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Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

ENGINEERING USES OF SONNE STRIP PHOTOGRAPHY[a]

John H. Wolvin[1]
(Proc. Paper 1668)

The Sonne continuous strip camera permits large scale direct aerial photography for detailed study of terrain features. Improvements in the camera and its support equipments were continually made during the war years. At that time, the camera was extensively employed for beach reconnaissance and water depth determination, as well as detailed bomb damage assessment photography. More recent research has added improvements to the equipment enabling it to be used in support of engineering projects.

Most engineering applications are best solved by stereoscopic coverage, although the camera is capable of either stereo or non-stereo photography. It is highly possible that recognition of ground objects is increased a factor of three with stereoscopic coverage compared with the non-stereoscopic photography.

Before dealing with the applications of the photography, it is best to understand the basic principles of operation and the design features by which stereo coverage is assured. Fig. 1 shows a perspective schematic of the camera geometry. A narrow, mechanically adjustable slit lies across the width of the film near the focal plane of a pair of lenses. The straight slit opening, which can be adjusted to be as narrow as 0.010 inch, limits the field of view of each lens to a narrow rectangular area on the ground with the longer dimension across the line of flight.

To achieve stereoscopic photography, each lens is moved away from the slit. The right one forward and the left one aft, until the fields of view of each are well separated in the direction of flight. The half film width in the focal plane of the right lens will record a ground object before the airplane passes over it and the other half of the film will record the same ground object, through the left lens, after the airplane has passed. A stereoscopic pair of photographs results.

Most important in the performance of the photography is synchronization of film velocity with that of the ground image. The film lies behind the slit in the focal plane of the lenses. It is given a velocity to eliminate relative motion

Note: Discussion open until November 1, 1958. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1668 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 2, June, 1958.

a. Presented at the ASCE Convention, Pipeline Division, February 24, 1958-

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between the image of ground objects and its surface. The picture is literally laid on the film eliminating blur due to the forward motion of the airplane. Nearly perfect synchronization can be achieved, but only by complex optical and electronic components of the camera system which sense the apparent angular velocity of the ground, automatically compensating for airplane velocity or altitude changes.

With this basic description of design features, much can be understood concerning performance on engineering applications. Because of the nature of the photography, it is best suited to coverage of continuous strips on the ground rather than large areas. Pipe and transmission line routes are excellent examples of optimized applications. Railroad and highway right-of-ways are also well suited for the photography. Largely due to the current widespread interest in expediting highway work, most of the recent applications have been in this field.

The continuous photography of the ground is only as accurate as the pilot can hold the aircraft. If on a curving road, for example, the aircraft were to fly the curve, the photography would show the road as relatively straight. Except for special applications, each flight line must be straight and tangents to curves, must be flown to prevent distortion of the ground image.

In performing the aerial photography two items must be given primary consideration; namely, altitude control and centering control. Mean ground elevation must be determined for flight line planning to control the aircraft clearance above the ground. The barometric altitude of the aircraft can be held within 50 feet, however, if on a straight photographic run the ground elevation were to change, a corresponding change in photographic scale would result. The aircraft should only be flown straight and level.

Centering of the flight line can normally be held within 1/10 of the altitude, regardless of the photographic scale. Three independent factors effect the scale, aircraft altitude above ground, focal length of the lenses and accuracy of image synchronization. A loss of accuracy in film synchronization means a change of scale in only one direction—the flight direction. If the film velocity is 5 per cent too fast objects will be stretched 5 per cent.

Focal length, as it effects scale is an invariant, but altitude is not. Flight lines are held parallel to a sea level datum, so as ground elevations change, the scale changes proportional to the aircraft clearance above the ground. Excessive scale changes due to steadily changing ground elevations, may be eliminated by several shorter flight lines.

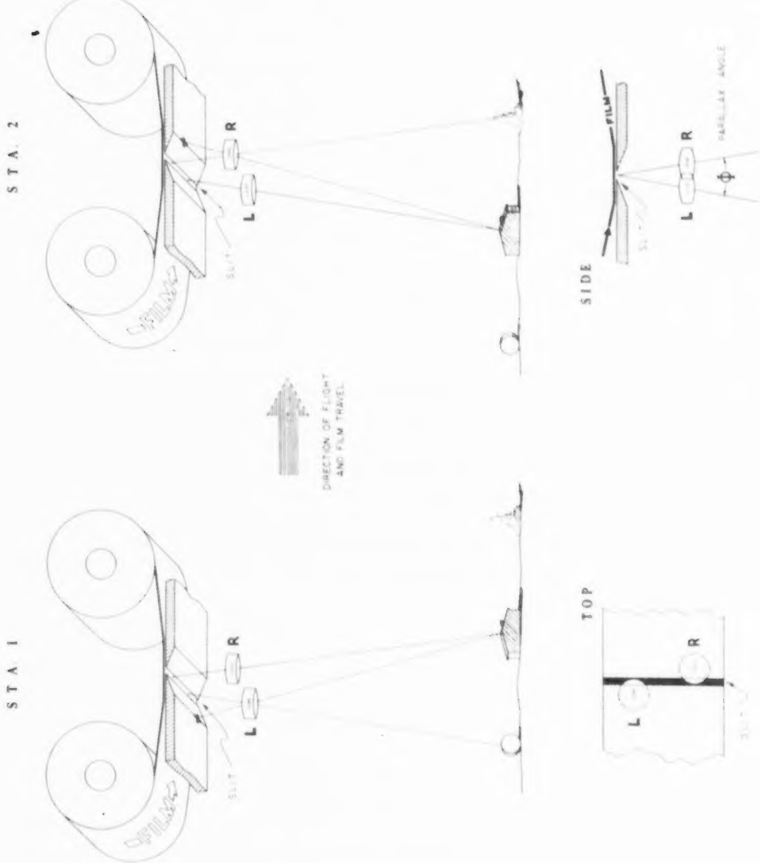
Continuous strip photography supplements rather than replaces precision mapping photography. Its primary advantage is ground detail and so currently applied is performed at large scales, for example, 400 feet per inch and larger. Because of its fidelity, enlargements up to 10 times may be made with comparatively small loss in detail. Much of the highway photography has been flown at scales of 100 feet per inch and 250 feet per inch. Sections of railroad have recently been photographed at scales as large as 15 feet per inch. The limit on large scale is imposed by the difficulties of low altitude flight rather than by limitations of the equipment.

As noted in Fig. 1, the camera construction assures stereoscopic coverage. The ability to adjust the positions of the lenses relative to the slit makes the stereoscopic parallax angle or the degree of vertical exaggeration variable. Most commercial applications of the photography have been performed with a stereo base less than 0.1 the altitude. Angles of this magnitude of convergence have been very reasonable for the primary intended use, i.e.,

large scale examination of ground features. When viewed stereoscopically in either the Sonne Viewer or Projector. The vertical exaggeration resulting from a convergence angle of 4 to 5 degrees definitely enhances the recognition of ground objects. These convergence angles are considerably less than those used in photogrammetric mapping.

Continuous strip photography offers the possibilities of certain types of precise ground measurements. Assume even that the photographic scale in the direction of flight is constantly changing due to either changes in the aircrafts clearance above the ground or slight errors in film synchronization. Scale across the flight is predictable and measurable, the image being recorded in an instant of time rather than integrated with respect to time. By means of appropriate parallax measuring instruments cross sections may be measured and plotted. Even limited ground control will enhance the accuracy of such measurements; however, in those applications where a known width can be scaled across the photograph a cross section can be made. A known width could be the width of the highway or bridge or the gauge of a railroad track. The width constitutes horizontal control and enables scale to be determined. If the camera is vertical or nearly so at the time of the exposure, relative elevations can be measured with no additional control. Assuming a camera tilt and specifically one about the roll axis of the aircraft, a single line of side levels and a line of levels on the centerline will control the otherwise tilted cross-section.

An additional feature, one which effects the sensitivity of altimetric measurements is the ability to use larger than normal base-height ratios. Each lens is displaced a distance from the slit which nearly equals its picture coverage. Fig. 2 shows a comparison of base-height geometry between a conventional wide angle mapping camera and a pair of the same lenses on a Sonne Camera. Base-height ratios of double that normally used can be obtained. This means that for the same scale of photography it is possible to obtain twice the accuracy of vertical readings with a correctly designed parallax measuring instrument.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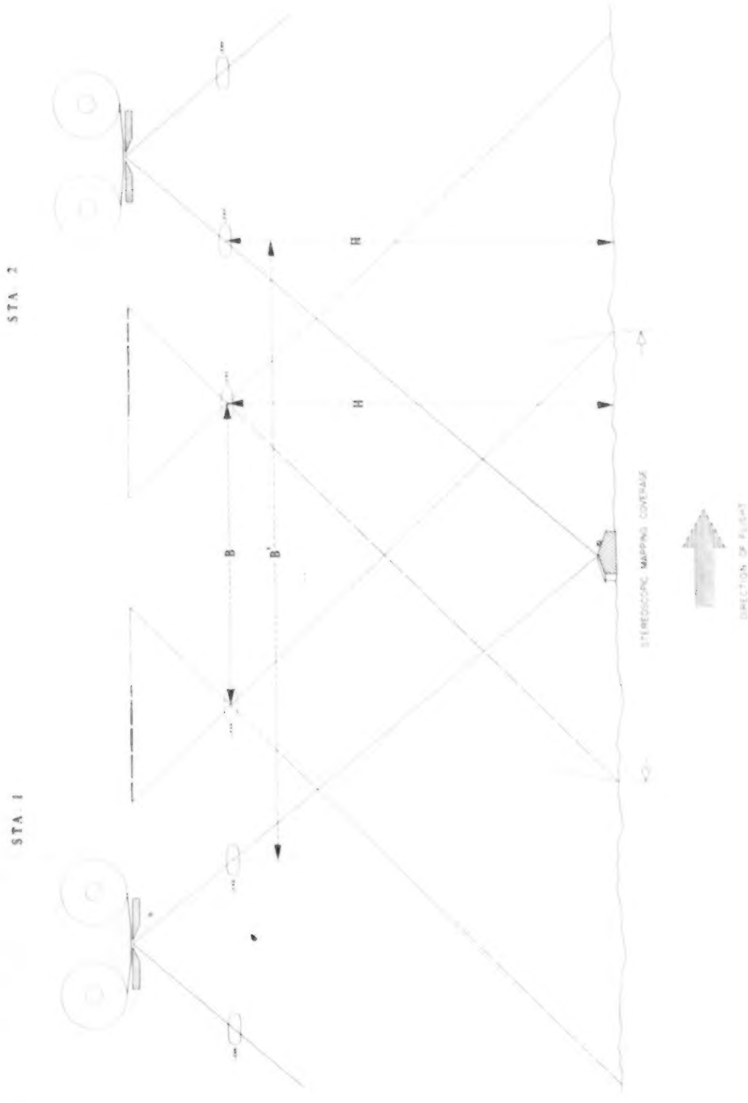
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AND FILM TRAVEL

Paper 1673 June, 1958 PL 2

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

PIPELINE FIELD WELDING AND QUALITY CONTROL METHODS[a]

A. G. Barkow[1]
(Proc. Paper 1673)

SYNOPSIS

Pipeline laying practice in America has progressed from raw field experience to recognized engineering technology.

The use of pipeline transportation was started in 1821 and now has developed into a vast network covering all sections of the country. Oxyacetylene welding in pipelines was started in 1911 and electric arc welding in 1922.

Pipeline welding is a three-stage integrated process using technique unique to this type of fabrication. Speed and mobility of the welding crews are outstanding features.

Manual welding by highly skilled operators working at specialized tasks promotes the exacting quality necessary in pipeline work. Automatic welding methods are being used to a limited extent. New welding processes and electrodes are continually being explored.

Most pipeline equipment is field-developed. Line-up clamps are an outstanding example of such equipment. Cautions must be practiced to avoid unfavorable conditions which might prove harmful to a weld.

Procedure and welders are qualified under strict supervision and disqualification may result from unsatisfactory technique. Nondestructive testing includes radiography, magnetic, supersonic, dye penetrant, and pressure testing. Radiographic inspection has helped greatly to improve welding.

Technical investigations in new material and processes present a real challenge to the engineering profession. Codes and Standards control all phases of pipeline work from the material being used to the installation of the line.

Pipeline building is a growing industry that looks to the engineering profession for guidance.

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a. Presented at a meeting of the ASCE, Chicago, Ill., February, 1958.

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General

The pipeline industry started as an outgrowth of necessity in transporting petroleum liquids and gases from the wellhead to the market.

In these early days pipelines were laid without the help of elaborate engineering studies and depended on the experience of the construction men. Organized engineering practices in this field have brought about a realization that pipelining has changed from an art to a science.

In other words, the sheer brawn and individual knowhow of the spread man has been replaced by recognized engineering practices; accurate aerial and ground surveys; scientific studies of terrain, soil, and rock conditions; weather and water data as gathered by the Weather Bureau; and design conditions.

Material is no longer just pipe and fittings. Field work is no longer just welding, coating, and lowering into a ditch. Pipe and fittings are purchased in accordance with well-developed standards and based on predetermined desired properties in accordance with operating demands. Pipeline construction is controlled not only by individual specifications but by recognized codes and standards.

Welding, as one of the prime functions, is served by a specific standard, designed to produce the highest quality workmanship consistent with economic practices. This standard—known as API Std. 1104—"Specification for Field Welding of Pipelines"—has been used widely for construction of pipelines in this country as well as in Europe and Asia.

The standard covers all phases of welding and testing—both physical and nondestructive. Since this standard might be considered the primer of pipeline construction, it will be used as the basis of this discussion.

History

It might be interesting to review the history of pipelining momentarily. This method of transportation is frequently classified as something entirely new, and, in a sense, rightly so. However, it is axiomatic that there is really nothing new under the sun.

Pipelining in like manner may point with pride to the fact that gas was transmitted through pipelines 400 years B.C., when the ancient Chinese brought gas from "burning springs" through bamboo logs to the sea coast to evaporate salt water.

The first pipeline to be laid in this country was a hollow log line from Canadaway Creek to nearby houses in Fredonia, New York, in 1821. First industrial use of natural gas—to evaporate salt brine—was at Centerville, Pennsylvania, in 1840.

By the time the first iron pipeline was laid in 1872, gas had been discovered in various parts of Pennsylvania and Kansas. By 1884 Pittsburgh had 335 miles of gas distribution system and supplied 250 million cubic feet per day.

The first high pressure, long distance line was built in 1891 from Greentown, Indiana, to Chicago, a distance of 120 miles and operated at 525 psi.

By 1900 natural gas had been discovered in 17 states with production valued at more than $25 million. By 1909 a number of pipelines had been put into operation, among them a 16-inch line to Joplin, Missouri, and a 183-mile, 20-inch line to Cincinnati from West Virginia.

The year 1911 ushered in the first application of oxyacetylene welding of pipelines on an 11-mile line to Philadelphia. In 1926 the era of long distance, large diameter, high pressure pipelines came into full swing, with the completion of a 22-inch, 170-mile line to Baton Rouge. It operated at 350 psi.

The following year saw the advent of high strength, large diameter, electric welded line pipe. This large diameter pipe, with comparatively light wall, made long distance lines economically feasible.

Pipelines then extended to all parts of the country. In 1931 two long distance lines were completed, the 900-mile Natural Gas Pipeline Company of America line from the Panhandle field in Texas to Chicago; and the equally long Panhandle Eastern line extending from the same area to Muncie, Indiana, and later to Detroit.

The depression of the '30s slowed the industrial expansion, but the war years saw the building of the now famous "Little and Big Inch" lines and many other mammoth lines, including an 1840-mile line from Texas to New York. Now, there are actually many more miles of pipelines than railroads.

To review, it was noted that the introduction of acetylene welding (Fig. 1) to pipeline work took place in 1911. Electric welding was first introduced in 1922 on a short line laid at Caney, Kansas. This line "leaked like a sieve," but welding improved rapidly, and by 1928 a 169-mile line was welded electrically (Fig. 2) by advanced pipeline technique.

At that time anything went for weld rod including the farmers' fences, but that also was short-lived. By 1930 the shielded electrode was on the job.

Soon many of the old "gas welding" ideas fell by the wayside. First, the back-up ring was eliminated. Then roll welding (Fig. 3) dropped off in favor of stove pipe welding, where one joint after another was welded to make mile-long strings, rather than three or four joint strings.

And so welding gradually has improved until today we see modern equipment (Fig. 4) and quality control at work, including radiography and other nondestructive methods to be considered later in this discussion.

Welding

In modern pipeline welding, acetylene still finds its use in small diameter, thin wall pipe, such as are used around pumping or compressor stations, meter settings, and similar work.

Its most important role is played in the cutting torch and here it still is an indispensible tool. With steels of higher chemistry and with all-weather work, acetylene also is finding a new field in preheating. With a slightly oxidizing flame it does not leave a carbon deposit on the beveled face, thus leaving a clean surface to work with.

Acetylene also has been used as the heating unit for a flash butt weld in experimental work, but this process has not been developed to practical application as yet.

Manual electric arc welding using the common shielded electrodes of the all positions E6010 and E7010 classification is the general practice in field welding today. However, the art of field welding is not "common," and it may still be regarded as an "art."

Field welding is as different from ordinary pipe welding as night is from day. Two important features in field welding techniques are most obvious. First, the field welder uses a stationary downhill method (Fig. 5) starting at

Fig. 1 Acetylene welding rig used in 1930 and 31

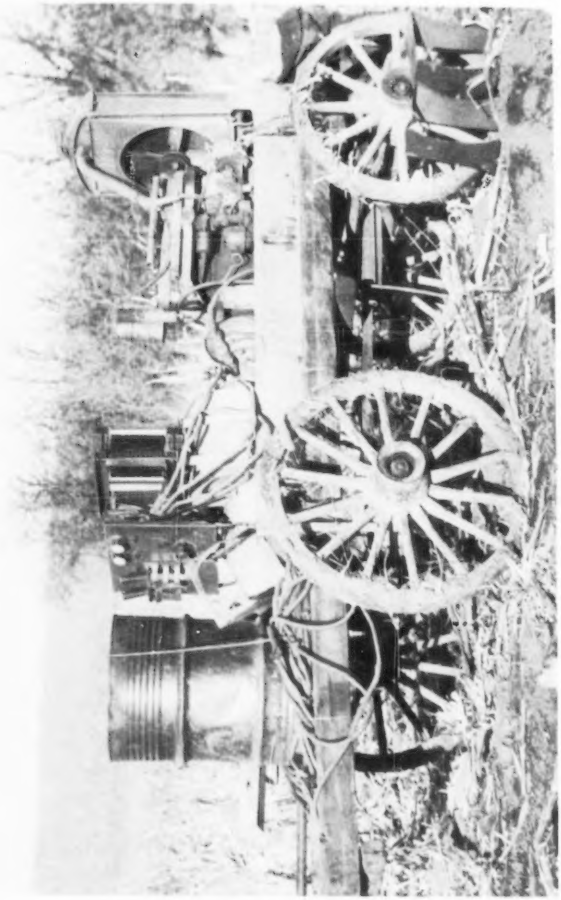

Fig. 2 Electric arc welding rig used in 1930 and 31

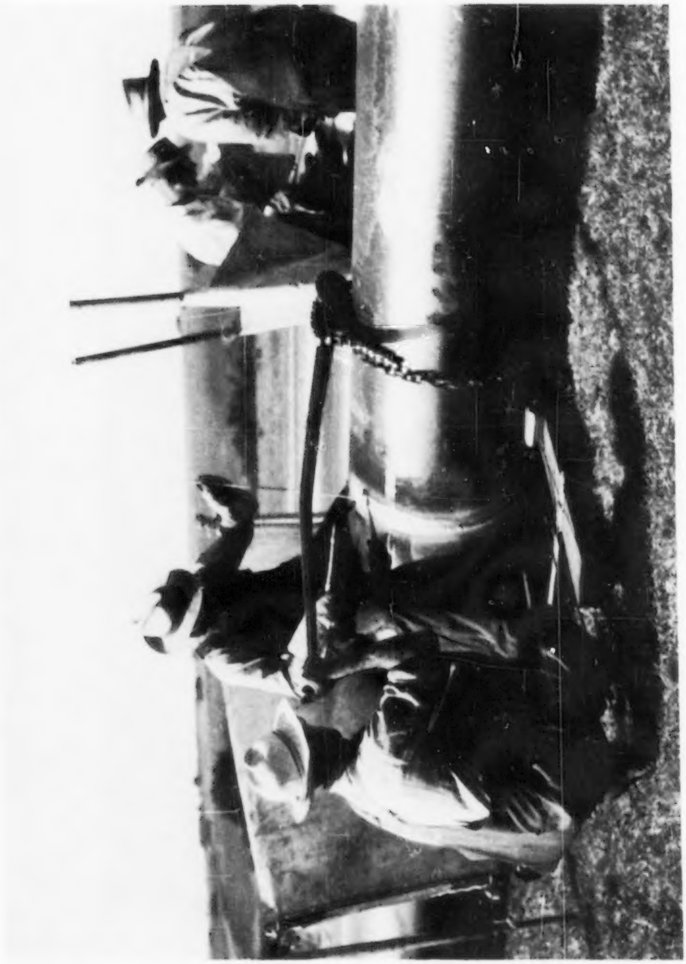

Fig. 3 Acetylene welding. Note arrangement for rotating pipe.

Fig. 4 Modern stringer bead and hot pass welding crew

Fig. 5 Modern electric weld on bottom of pipe.

the top of the pipe and working downward. Second, arc amperage is considerably higher than is normally used, and, consequently, the speed is considerably greater. In fact, arc travel speed usually astounds the pipe fitting welder.

With all these contradictions to ordinary welding technique, the finished weld (Fig. 6) is equal to and, in many cases, superior to shop welding. Besides these radical changes in technique, field welding practice has developed a unique production method that permits greater mobility of the welding crew.

Field welding is really divided into three operations, each complimenting the other. The first group of welders, referred to as stringer bead welders, consists of either two, three, or four welders (Fig. 7) who do nothing but lay in the first bead. It is a novel experience to see four men welding (Fig. 8) on a stringer bead of 30-inch or 36-inch pipe, all working simultaneously. Usually two welders are right-handed and two are left-handed. This work is done with machine-like precision.

To compliment the stringer bead welders, it is necessary to mention another group of craftsmen, the line-up crew. These men line up the joint (Fig. 9) to a precise gap between the two pipes and clamp the pipe tight with an internal line up clamp. The gap may range from dime to nickle width, depending on the welder's choice. Dime-width is used most frequently.

No tack welds are used, but step welding is common practice. Here the welders use one-rod-length beads, working in opposite quarters and step upward or downward depending on the side being welded.

To clarify this method, the procedure of a two-man crew might be considered. One welder will start at about 1 o'clock on the periphery and weld to 3. (Pipeline jargon for locating points on the periphery of a girth seam.) In the meantime, the other welder is welding from 8 o'clock to 6. The first will then weld from 4 o'clock to 6 making sure of a good bottom lap, while the second welds from 12 o'clock to 10. Finally both welders will finish the sides.

Such a procedure is used to minimize shrinkage and prevent closing of the welding gap. This whole procedure, from lining-up a joint to completion of the stringer bead, takes far less time than it has taken to discuss.

A good stringer bead welder will make a weld with a smooth, even internal bead about 1/16-inch high and about 3/16-inches wide. The bead will be so smooth that few who have not seen this work before will believe that the bead was put in from the opposite side. Stringer bead welders are top hands and are recognized as such by the welding fraternity.

A second group of expert welders now move in—"the hot pass welders." They, too, work in groups of two or four, usually two to a weld, leapfrogging each other. This crew puts in the second pass and thus builds the weld to a self-sustaining strength. The hot pass crew immediately follows the stringer bead crew so that the weld does not have an opportunity to cool, thereby taking advantage of the residual welding heat.

This second pass not only strengthens the weld with added metal but repairs any gaps or "windows" left by the stringer bead men. The heat of the second metal application also produces a stress relieving heat treatment in the first pass metal deposit which prevents cracking and reduces welding stress. This crew again leaves the uncompleted weld after its special task and moves forward. The third crew of finish welders follows further behind and actually finishes the weld (Fig. 10).

Typical field welding procedure calls for one bead for each 1/8-inch of metal thickness, plus the root and cover pass. Thus a typical 3/8-inch wall pipe would require five passes. Frequently an extra stripper pass is used on

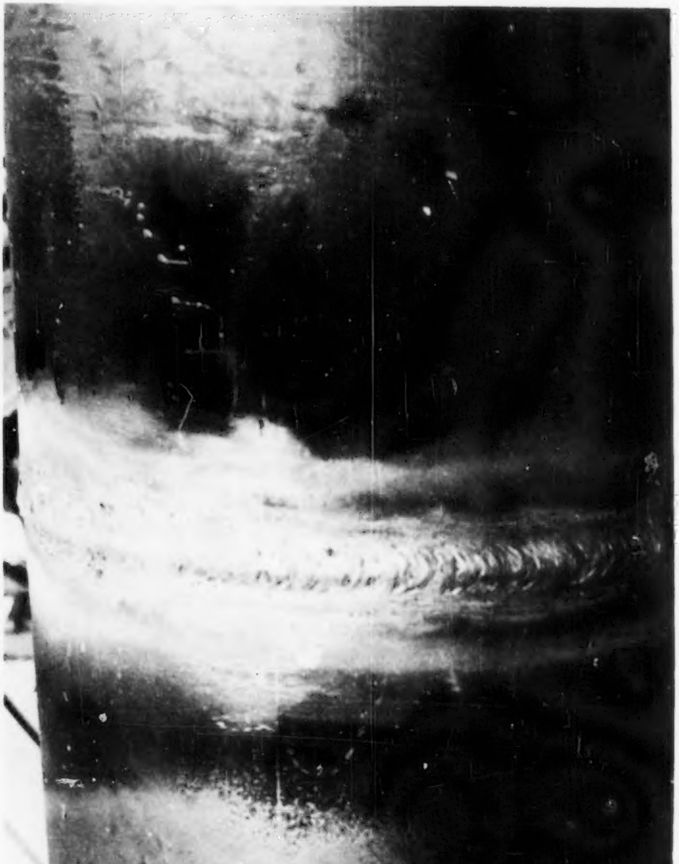

Fig. 6 Completed girth weld.

Fig. 7 Four men simultaneously welding stringer bead.
Fourth man on opposite side of pipe.

Fig. 8 Four man crew welding stringer bead.

Fig. 9 Line up crew maneuvering pipe into place. Note internal line up clamp in place.

Fig. 10 Line of final welders

both sides to help fill the groove. This stripper pass usually runs from 2 o'clock to 4 and from 10 o'clock to 8, and is made before the final cover pass.

Before discussing further the technique of welding it is desirable to comment on another segment of the welding crew—the welder's helpers who clean the bevels before starting the actual welds and who clean between beads.

Cleaning (Fig. 11) is not simply another chore that can be done as a matter of procedure. A great deal of weld quality depends on the thoroughness of cleaning and preparation between passes. Many inferior welds could be saved by proper preparation. A little chipping of holes or high spots, a few extra jabs of ice picks in under cuts and stag pockets, a little grinding, and a little more care will save hundreds of dollars for the contractor in the salvage of potentially inferior welds. Speed is a commendable asset in pipeline welding, but haste in cleaning makes waste.

To discuss the technique of pipeline welding, it is essential to consider the welding generator. Commonly used generators are either gasoline or diesel-driven, portable D. C. welders of 300 amp rating. Arc current and stability require smooth, constant, and instantaneous action.

Thus weld quality actually starts at the generator. This then is the starting point of weld inspection. The welding inspector frequently checks the generators, and has the power to remove a machine from the line as readily as he would an unsatisfactory welder.

Pipeline welding is probably the only method that condones the practice of mixing electrodes for carbon steel welds. In pipeline welding the E6010 type rod is used for the stringer bead because of its greater ductility under movement of the pipe. E7010 type electrode is used for the remaining passes to secure desired strength. The cover pass may be made with an E6010 electrode to improve appearance and contour.

This practice was started by pipeline welders through field tests and research so that the most advantageous physical properties could be produced in each layer of weld metal. These properties include ductility at the root, strength in the body, and smoothness in the cover.

In contrast to power piping welding and shop fabrications of piping, the two outstanding features of field welding are: (a) the downhill method and, (b) the comparatively narrow weld.

Downhill welding—that is, starting at the top in a stationary work position and working around the pipe to the bottom—allows for greater arc speed in a narrower groove. A very short arc is maintained and the root pass is made by burning through the adjoining lips in such a manner that the puddle fills the gap to produce a full, smooth inside bead. A high degree of skill is required to proceed at a rate of speed that will maintain the opening and puddle relationship in such a manner that no arc break, causing a "window" or a lack of full penetration, results.

The welder must respond instantly to any fluctuation in arc voltage and most stringer bead welders can do that almost with the accuracy of an electronic control. Stringer bead welding rate is between 20 and 30 inches per minute.

The second pass, commonly referred to as the "hot pass," is similarly welded at a high rate of speed. The art in this pass is to wash out any defects left in the root pass and to produce a solid foundation for the completion of the weld.

Many of you wonder why some type of automatic welding has not been adopted to pipeline welding. The answer is simply that there does not yet

Fig. 11 Cleaning between beads.

exist, for cross country welding, an automatic process with the necessary speed and flexibility comparable to that obtained by the manual procedure. Numerous attempts have been made to adopt automatic welding to pipelines but with little success.

Some years ago a pressure butt welding method was developed in which the ends of the pipe were heated with gas flames to an advanced plastic state. The pipe then was "bumped" together to achieve fusion.

The unsolved problem with this method was the holding of the pipe in proper alignment during the "bumping" process.

Submerged arc welding, successfully used for the longitudinal seam, is being adopted to "rail head welding"—a method of butt welding two joints of pipe at a central location before stringing. This method has a fairly successful history and does speed progress in the field since the same number of field welds will give twice the footage. Difficulty, however, has been encountered in producing a sound stringer bead without a back-up ring. Manual first passes are commonly used, making this method partially dependent on manual welding.

The most recent development in this field is a submerged arc process (Fig. 12) in which the outside beads are welded first with use of a relatively heavy band. The inside bead (Fig. 13) then is made by the same process, using an automatic head held by a boom and which is manually guided by an operator riding the boom. This is the first fully automatic machine-made girth weld. But this process is still only applicable to double jointing.

A great deal of experimental work is being done in this field, particularly in view of the shortage of fully experienced stringer bead welders. A process that may hold the answer is the shielded inert gas metal arc process which at present is finding widespread application in other fields of welding. No actual field trials have been made with this process although it has been unsuccessfully used for prefabricated pipe welding in fabricator plants.

Welding electrodes, other than those mentioned above, also are being investigated for possible application. Among the latest developments in this field are the low hydrogen and iron powder contact electrodes. The need for a control of notch sensitivity and under bead cracking makes the use of low hydrogen electrodes very desirable.

The low-hydrogen iron powder contact electrodes find some application where downhand welding can be used. This is particularly true in the welding of sleeves, saddles, pads, and other pipeline attachments. It, therefore, is evident that pipeline welding is a living, dynamic science, and that great strides toward improved welding are imminent.

Internal Lineup

Pipeline equipment is frequently a development of the practical field man and as such has been "engineered" by non-engineers. Improvements and refinements have been added by trained equipment engineers after the basic developments were proven in actual usage.

One of the most ingenious of these tools, and one that added greatly to the improvement of welding, is the internal lineup clamp. The internal lineup clamp is an expanding device that is fitted under the mating ends of the pipes and holds them firmly in place for welding.

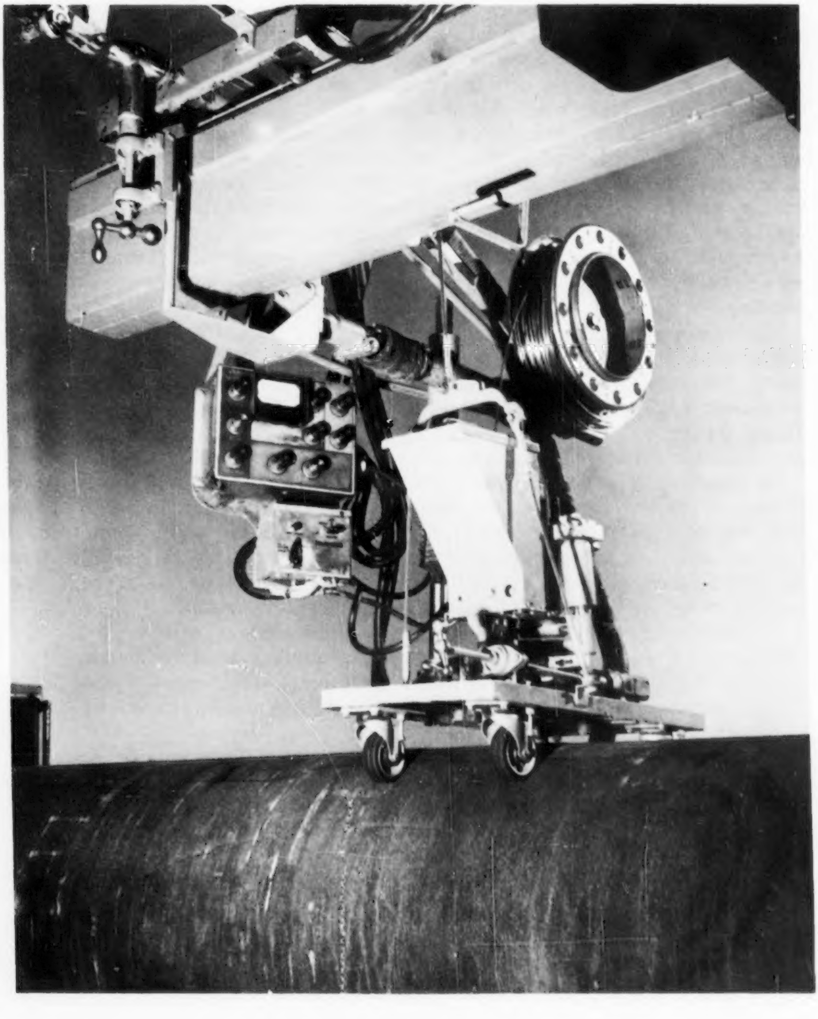

Fig. 12

Fig. 13

The twin advantage of this device is that it eliminates the need for tack welds and helps level the mating edges, thus minimizing miss-match or, as popularly referred to, "hi-lo". The earliest model was a hand-cracked device (Fig. 14) in which a screw and lever arm forced shoe segments against the pipe inner surface.

Later developments introduced electric motive power, hydraulic pressure, and pneumatic power (Fig. 15). The shoes also developed from a simple split band to the latest, having a large number of small round fingers acting in individual small surface areas. The latest clamp successfully rounds out adjoining edges to give a near perfect welding groove.

A word of caution regarding high pressure line-up clamps should be mentioned at this point. Any major rounding out of pipe in the field, where a permanent set cannot be achieved to hold this roundness, produces a locket-up mechanical strain in the stringer bead in addition to the normal welding stresses. In welding the second bead the strength of the stringer bead momentarily is reduced to a very low level, at which time the superimposed bending stresses may instigate root bead cracks.

It, therefore, is a fallacy to believe that a pipe does not have to be perfectly round when it leaves the pipe mill. Pipe will crush slightly during shipment, but out-of-roundness at the pipe mill is almost inexcusable. Very little pipe in pipeline use has a diameter-wall ratio of a degree that it will not maintain roundness within itself.

Returning to the line-up clamp, and particularly to its use in welding of large diameter line pipe another hazard must be considered. As noted before, the line-up clamp does set up a strain in the pipe wall. Releasing the pressure causes a "spring back." It has been noted that weld metal has comparatively little strength until it has cooled below the critical temperature. From the study of metallurgy it may be noted that metal of line pipe composition passes through a second critical stage at about 600° F, known as the Blue Brittle Range. Knowing these facts it readily can be seen that superimposed loads during these transition periods can instigate fractures. The external load caused by lowering pipe onto skids after welding, added to the locked up stresses caused by reforming out-of-roundness pipe, may be sufficient to cause fissures in those sections of a weld metal that have not passed through the transition temperature ranges.

Knowing this, it is highly recommended that the tension of the line-up clamp be maintained until the root bead is completed and the pipe has been rested properly. The line-up clamp lends support against the shock of landing the pipe, and the time interval of the operation permits all sections of the weld to pass through the danger zones before the spring back load is affected.

By observing these cautions, much of the so-called "under bead cracking" trouble can be avoided. There are a number of cautionary points important to sound welding practices, but time does not permit discussing them.

Qualification of Process and Welders

Pipeline welding follows the method of qualification set up in the Standard for Field Welding of Pipelines. Since the essential factors of pipeline welding vary from normal, procedure qualification is based on pipe size, wall thickness, bevel design, climatic conditions, etc., rather than material groups, as specified in other standards.

Fig. 14 Hydraulic internal line up clamp.

Fig. 15 Pneumatic line up clamp.

Pipeline procedures recognize only two groups of materials, both of which normally would fall into AWS Classification P-1. Normally one position is used in all qualification procedures. This is the "horizontal stationary," in which the weld groove is actually vertical and all positions are encountered.

Welder qualification is by far the most important consideration, since the pipeline welder is naturally more on his own in actual production. Although pipeline welding is divided into three separate operations as described previously, each welder is qualified on a complete weld.

His welding technique is observed and the test may be terminated before completion of the weld if the inspector feels that the weld does not meet standard performance requirements. Frequently such disqualification occurs during the preparation and welding of the root or second bead. A welder who is thus "looked out" cannot take another test. If the weld is completed and "looks" satisfactory, test coupons are cut (Fig. 16) from its periphery and subjected to tension, root (Fig. 17) and face bend and nick-break (Fig. 18) tests.

Failures of physical tests within the acceptable limits of the standard may not cause disqualification, but most often one specimen failure is sufficient for disqualification and only rarely is a welder given a second chance.

Welds also are cut periodically from the actual line and tested as prescribed above. A failure of any one specimen terminates the welder's qualification for the job and he is immediately released. This method of control tends to support the quality of each weld.

This practice is probably the chief difference between shop quality control and field quality control and makes the welder solely responsible for the quality of his welding. With such a practice it is little wonder that all welders must be specialists in pipeline welding. Non-experienced pipeline welders seldom, if ever, can fit into a pipeline spread.

It is interesting to note, in passing, that a special pipeline welders' union local has been set up for pipeline welders operating all over the country. This union takes precedence over all other welder unions, thus giving an interference-free reign to welders passing from one locally controlled union district to another.

Nondestructive Testing

Pipeline welding quality is controlled also by the much more searching methods of nondestructive testing. The "impossible" was achieved when radiography, both X-ray and gamma-ray, was adapted to field conditions. At the time X-ray was first considered, the equipment was monstrous and most X-ray engineers shook their heads at the idea. However, equipment meeting the requirements for pipeline application was developed on a principle far removed from that then in use.

The X-ray tube and necessary electrical compliment were made smaller without reducing the power and the whole apparatus, with the exception of the controls, was incased in a "pig" (Fig. 19). This pig then was mounted on a carrier, and with a power tractor attached (Fig. 20), was ready to be run inside pipe 20 inches and larger in diameter.

Later models were made to go into pipe 12 inches in diameter. Sundry—and often ingenious—appurtenances made it possible for the pig to travel as much as a quarter-mile through a solidly welded line, stopping to radiograph each weld and then coming back out again.

Fig. 16 Coating specimens for welding test.

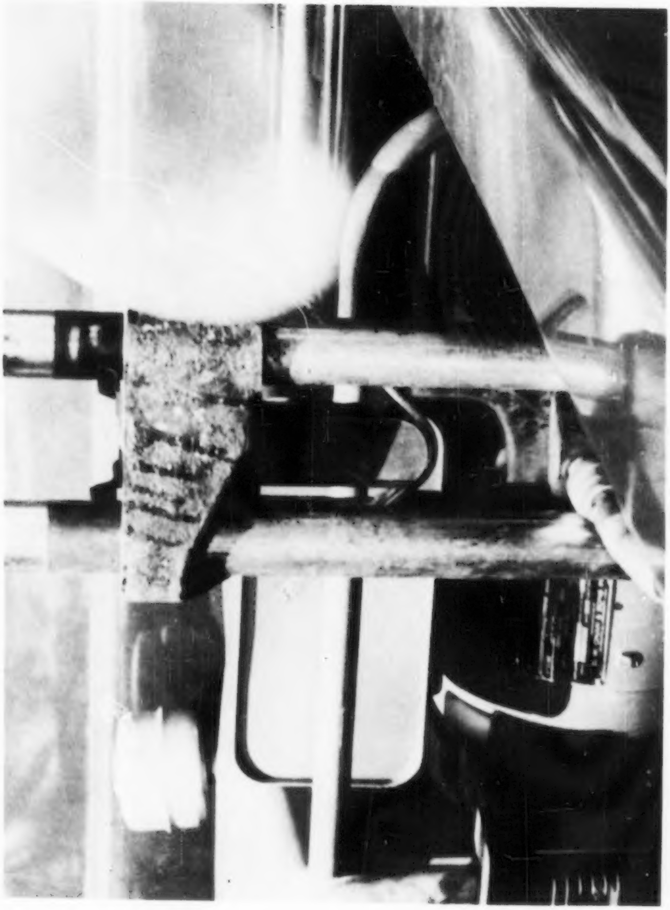

Fig. 17 Band testing.

Fig. 18 Tension testing.

Fig. 19 Radiographic pig carrying X-Ray tube.

Fig. 20 Tractor unit for radiographic equipment

As isotopes became available, they also were adapted to pipeline radiography. First the isotope of cobalt, then iridium, and later cesium. Other isotopes also are being explored.

Not only has radiographic equipment been taken to the field, but also the processing laboratory—dark room, developing tanks, washing and film drying, and power plant. All this equipment is mounted on a truck for portability. This truck follows in line of progression immediately behind the welders.

Very few minutes after the weld is completed, the welding inspector (Fig. 21) can look at the developed film and instigate necessary corrections. A pattern of defects or poor welding procedure can be discovered and corrected before reaching a serious condition which would cause rejection of welds.

Recognizing the value of radiography, standards also have been developed covering radiographic technique, film processing, radiation safety, interpretations of film, and acceptability limits for defects.

It must be recognized that all welds are not perfect, homogeneous, and free of inclusions and voids, but neither is the steel plate of the pipe body. It also is recognized that all defects are not harmful to the same degree and that a certain amount of discontinuity can be tolerated.

Therefore, limits in tolerable defect sizes and distribution have been developed. Defects of a greater magnitude may be repaired if it is possible and economically feasible to do so, or the entire weld may be removed from the line.

The application of radiographic examination to welding has been phenomenal in the improvement of weld quality. As an example, one line of several hundred miles was laid before radiographic control was used, and weld leaks were found on an average of one per mile. In one section of 30 or 40 miles an even greater concentration occurred. On another line of 1400 miles, using about 25 per cent radiographic coverage, only six defects were found. This would tend to prove that thorough radiographic coverage pays, regardless of the additional cost.

Nondestructive testing, however, is not confined to radiographic coverage alone. Magnetic inspection, ultrasonic inspection, dyepenetrant inspection, and pressure testing are playing increasingly greater parts in proving a pipeline before it is placed into service.

Recent developments in magnetic inspection (Fig. 22) and field tests of this method indicate that major defects can be detected even if they are not visible or are subsurface. While this method is not as conclusive as radiographic inspection, it has the advantage of greater ease in application and greater speed of determination of results.

Using magnetic powder (Fig. 23), the defects are located on the exact location of the weld for examination. The indications also can be preserved by transfer to an adhesive belt, thus producing a record quite similar to the radiographic film.

This application is still in an embryo stage, but it does have a bright potential and may compensate for its disadvantages by a greater coverage.

Ultrasonic inspection likewise has a potential use in weld inspection, but has not been developed for a truly successful application as yet. However, it does find an advantageous application in determination of pipe wall soundness and pipe wall thickness for installation of taps on other welding on pipelines in service. Here it can find laminations and dangerous conditions before the welder strikes an arc to the pipe.

Fig. 21 Radiographic technician examining film.

Fig. 22 Magnetic inspection of pipeline welds.
(Courtesy of Magnaflux Corporation)

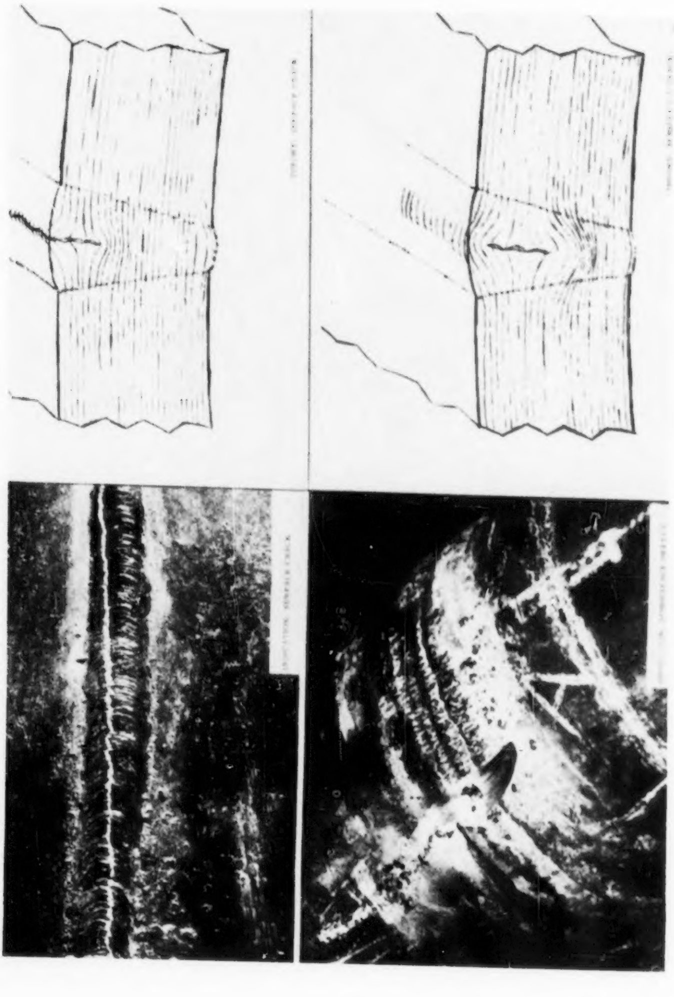

Fig. 23 Surface indications and schematic sketches of weld defects
(Courtesy of Magnaflux Corporation)

It therefore provides a safety factor for pipeline personnel which has met with phenomenal acceptance in this particular operation. Ultrasonic inspection similarly has found its place in examination of piston shafts, crank shafts, fly wheels, and other engine equipment, where defects have been detected before actual equipment failure occurred.

Dyepenetrants have been used in all types of inspection. Because of simplicity of application and rapid production of results, this method frequently is used in conjunction with repair welding to locate surface defects or to determine if defects have been completely removed by grinding and chipping.

Pressure testing, either hydraulic or pneumatic, is the old reliable proof test of any welded enclosure. It will not, however, be described further except to mention that it is being used in the final testing of cross-country pipelines, even when other methods of nondestructive testing have been employed.

New Developments

Pipelines are evermore stretching their slender tentacles to new oil and gas fields in mountains, under the oceans, into the frozen north, and to the steaming jungles of the tropics; to markets in all major and secondary cities of the nation. The large diameter pipe of 20 years ago is now paralleled again and again by even larger lines, and the vast deliveries of today have only scratched the surface of the potential market. Pipeline transportation is a young giant that is just awakening, and the future will astound even the most farsighted of today.

What materials does this future hold? The low alloy high strength steels already are becoming part of the picture. Materials having high corrosion resistance definitely are needed for transportation of corrosive materials. Yield strength of 100,000 psi minimum already is in the planning stage. Nonferrous alloys, such as aluminum, are being used experimentally. Plastics have appeared on the scene. Stainless clad steel may offer some advantages. Thus it can be realized that a wide variety of material is or will be available.

These new materials will require new construction methods, welding procedures, handling, and coating equipment. They will present challenging engineering problems, investigations, and acceptance studies. Future increased requirements for construction speed means more automatic equipment, more automatic welding, and more stringent quality control.

Welding technique also is developing in many directions—types of welding processes, new types of electrodes, new problems. All of these improvements are being studied by pipeline engineers and are being adopted as fast as they can be proven. The demands of the industry present real challenges to the engineering profession and the challenges are rapidly becoming realities because of the joint interest of the engineering fraternities such as the ASCE.

Codes—Standards

A growing industry must police itself to keep from going wild. The pipeline industry realized this and through various available agencies such as the American Petroleum Institute, the American Gas Association, and others, have set up standardization committees to develop codes which promote reasonable safety standards to be followed in construction and operation.

Just to mention a few of these standards, all pipe is manufactured in accordance with either API Std. 5L for carbon steel line pipe or API Std. 5LX for high strength line pipe. These standards specify the chemical and physical properties of various grades of steel skelp and seamless pipe. They also control manufacturing processes and specify quality control practices. They set forth test standards and limits of acceptability. Finally they provide a recognized identification mark.

Welding controls are based on API Std. 1104, which gives detailed instruction on development of procedures, testing of welders, design and welding practices, nondestructive testing, and limits of acceptability. It is actually the "field bible" in pipeline welding, therefore, and has gained world wide recognition.

Construction is based on ASA Std. B 31.1.8. This standard is the construction bible and guides the designer as well as field construction toward the building of safer, more economical pipelines and facilities. The standard covers all phases of construction and incorporates all other applicable standards and specifications.

Each of these standards could lead to lengthy discussion and, in fact, much has been written about them. The one outstanding feature of all of them is that they were written by practical operating engineers interested in all phases of pipelining. They represent the ultimate experience, knowledge, and understanding. They are factual statements that can be applied to construction and have been field tested. They are practical and yet conservative. They are authoritative to the point where they have been accepted in legislative codes of state regulatory bodies.

CONCLUSION

In conclusion it has been demonstrated that pipelining is a lusty industry—one that is growing more rapidly than any other form of transportation. Pipelining started from scratch with only a practical know-how, adopted engineering principles, technical developments and scientific practices as it developed, and now has gained the respect and admiration of large engineering groups.

The pipeliner today is not the hard-driving ruffian that he is pictured to be. The modern pipeliner is a specialist and a respectable citizen who is welcomed into the towns where headquarters are set up.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the encouragement and assistance of Messrs. Strong and Thompson in reviewing this paper and the editorial review of staff members of "Between the Lines." (Natural Gas Pipeline Company of America publication.)

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Journal of the

PIPELINE DIVISION

Proceedings of the American Society of Civil Engineers

FUTURE PROSPECTS FOR INTERNATIONAL PIPELINES[a]

William R. Connole[1]
(Proc. Paper 1674)

One of the baffling paradoxes of all time is the fact that petroleum wealth is located in some of the most remote corners of the nation and some of the most inaccessible parts of the world. Mankind seems to be engaged in a kind of mass treasure hunt, the rules of which were laid down ages and ages ago. Oil and gas are needed in New York, Boston, Washington, Chicago and San Francisco, to name but a few. It is found in Texas, Louisiana, Oklahoma. Oil is needed in Western Europe. It is found in the Middle East, Venezuela, Sumatra and even in the forbidding wastes of the Sahara Desert. Getting this oil and gas from where it is found to where it can be used is a true life romance that never ceases to astonish men and to spark their sense of adventure.

These efforts demonstrate the premise widely recognized by geopoliticians, military men, scientists and virtually all thinking men of our time that the fundamental measure of the extent of the success of modern material civilization is its ability to find and use energy. And fundamental to its success in finding and using energy is its success in mastering transportation problems. Energy and transportation—the two pillars on which our modern material civilization is erected.

Economists have a way of explaining how an inanimate thing like oil or gas lying unused and unwanted for ages can suddenly become so valuable and so important that whole civilizations will go to war over them. For the purposes of this discussion, however, they need not be reviewed. The simple fact is that natural gas remained locked in the sedimentary foundations of remote corners of our country and the world until something happened which made it possible and profitable for men to go after it.

The first thing that brought about this result was a prodigious increase in the demand for energy and the increasing reliance on fossil fuels for that energy. The second thing was the development of the means of carrying it cheaply from one place to another.

Note: Discussion open until November 1, 1958. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 1674 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 2, June, 1958.

a. Presented before the ASCE, February 24, 1958, Chicago, Ill.

1. Federal Power Commissioner, Washington, D. C.

It is no secret, that as recently as 1850, only a century ago, fossil fuels supplied only 5 per cent of the world's energy while men and animals were responsible for 94 per cent. Today 93 per cent of the world's energy is derived from coal, oil and natural gas. In fact, 5/6 of all the coal, oil and gas consumed since the beginning of the Fossil Fuel Age has been burned up in the last 55 years.

But the appetite for energy is one thing. The means of satisfying it is another. Until men mastered the techniques of transporting oil and natural gas from where it was to where it could be used, that appetite would never be satisfied. To the engineers of our time, the great bulk of credit for this achievement must go. Consider the natural gas pipelines. Here is a field in which truly staggering progress has been made in less than 20 years. The Federal Power Commission has certificated nearly 76,000 miles of pipeline in this country alone, able to deliver seventy billion therms of natural gas each year and stretching into every state in the Union with the exception of Vermont and Maine. To the pipelines then must go the credit for transforming a waste produce into one of the most valuable energy sources this country enjoys.

The basic idea of pipelines, then, is transportation--the transportation of energy. In America there is often too much emphasis on the pipelines' function of buying and selling natural gas. Unfortunately, this obscures the fundamental nature of a pipeline. The only reason a pipeline exists is to make natural gas more valuable than it was in the place it was found. In other words, the "utility of location," the traditional contribution of any transportation agency, has been added by the pipeline.

Of course the increase in value must be greater than the cost of moving the gas from here to there. Men of the engineering profession have succeeded in meeting the challenge of keeping that cost below that value, at least within the confines of the United States. But dramatic and intriguing challenges remain.

Natural gas is still landlocked and useless in some of the greatest reservoirs of energy in the world. When the pipeline engineers will solve the problems of getting natural gas out of the Middle East and across Southern Europe into the population centers of Western Europe or down into Africa is a question still to be resolved. When South and Central America will begin receiving the blessings of Venezuelan natural gas is also largely reserved for men of the engineering profession. Finally, when will the vast reserves of Northwestern and Western Canada be available in this country?

A look at the pipeline network in the United States superimposed on a map of continental North America is an interesting experience. If the map were a physical map and did not have political boundaries and if at the same time it showed the location of natural gas reserves, we would be struck by the absence of north-south pipelines connecting the Canadian reserves with sizeable population centers in the U. S. The reasons for this absence are simple and well known.

First of all, the existence and extent of these reserves is a very recent discovery. Secondly, the engineering and construction genius which could surmount frightening obstacles like the Canadian Rockies and the terrain north of the Great Lakes are recent developments. But now these two problems have been mastered. What then are the prospects of connecting the newly discovered reserves to markets in this country?

It is the writers belief that the prospects are excellent.

As an entirely theoretical matter, all the world's energy could be considered as one pool and all the world's consuming areas as taps drawing on that pool. As a practical common sense matter, however, this is no nearer possible than it is to look on the world's entire labor force as one pool and on the world's industries as taps on that pool.

Even on the North American continent practical, realistic, and entirely valid considerations make it extremely difficult to carry out the possible distribution of energy between Canada and the United States on a purely theoretical basis. But, because it is difficult it certainly is not impossible.

The respective national interests of Canada and this country must be observed. They must be respected. They must be given their fair weight in dealing with any attempt to distribute energy between the two countries. People must never lose sight of this fact and people must never belittle it. It is easy to do both, it is easy even to feel a certain measure of frustration when it is realized how few physical impediments stand in the way of constructing a pipeline network between the two countries.

The first step in achieving mutual respect for each other's best interest is for each to make sure what his own best interests are. Fortunately, both Canada and the United States are in a position to make this determination now. And even more fortunately this determination is being made during the period when construction is being proposed and not after it has become an accomplished fact.

It is entirely fitting and proper for the Canadian Government to undertake the sweeping study which is now being carried out by the Royal Commission on Energy Resources, commonly known as the Borden Commission. This Commission was set up with extremely broad and sweeping authority and is charged with the responsibility of making recommendations concerning policies for energy use which will best serve the national interest of Canada. It also will inquire into and make recommendations concerning the extent of authority that might best be conferred on a National Energy Board to administer such aspects of energy policy coming within the jurisdiction of Parliament as may be desirable to entrust to it.

It is entirely proper for that nation to adopt whatever policy best serves its own interest with respect to whether there is surplus gas not needed to bolster its own economy and if so, how and in what quantities should it be exported into the United States. The Dominion, and indeed, the Provinces are to be congratulated and commended for their wisdom and foresight for undertaking this project now.

By the same token, it is entirely fitting and proper for the United States to determine its own best interests and to consider the question of utilizing Canadian natural gas on terms which are best devised to encourage and further the best interests of the U. S.

In the writer's judgement the prospects for pipelines between Canada and this country are excellent. Certain physical and engineering problems have been met. The chances are that the mutual best interest of Canada and the United States will require some utilization of Canadian gas in American markets. For this reason the author feels that the remaining problems will be solved as efficiently and as satisfactorily.

There now exists ground rules for the construction of international pipelines between Canada and the United States. Also, some construction has been completed following these rules. Only by a knowledge of what has been

done so far will it be safe to expect what might happen in the future.

In this country the Natural Gas Act contains a section which gives to the Federal Power Commission authority over imports or exports of natural gas. The standard set out in that Section 3 states: "The Commission shall issue (an order authorizing exportation or importation) upon application unless after opportunity for hearing it finds that the proposed exportation or importation will not be consistent with the public interest." Notice that the Congressional mandate is not worded as a prohibition. It is worded affirmatively. The Commission is directed to issue a certificate unless it finds that to do so is contrary to the public interest. This is interpreted by the writer as an expression of congressional intent favorable to the authorization of international pipelines.

The Commission has not had many opportunities of invoking this statute. In fact, there are only four connections presently of any consequence between Canada and the United States. The only existing connections for importation of natural gas are between West Coast Transmission in Canada and Pacific Northwest Pipeline in Washington and, secondly, the connection to serve the plant of Anaconda Copper Company in Montana. Incidentally, this required the enactment of a special law by the legislature of the Province of Alberta. There are only two connections for the exportation of gas from the United States into Canada. These are in Detroit and at Niagara Falls. As a result, expressions of opinion or interpretation of policy are few in this area. Looking at the language of Opinion 271 of the Commission in the Pacific Northwest Pipeline Corporation case, as one example, this language if found: "We do not consider it to be in the public interest, however, to authorize a most important new project to serve a major area—involving a large and important segment of the American economy—which from the outset will be completely tied to and wholly dependent upon an exclusive source of supply entirely beyond the control of agencies of the United States." The later Opinion No. 289 in this matter did not materially change this statement.

For another statement of the policy of the Federal Power Commission it is necessary to go "south of the border," so to speak, and read the language written in Opinion No. 296 in the Texas Eastern Transmission case in which authority to import from Mexico was issued. Here the Commission said: "The importation of natural gas from Mexico is clearly not inconsistent with the public interest. All necessary authority to export the natural gas as proposed has been established of record. We view the importation as proposed as indicative of mutual benefit which our country and its neighbor to the South may receive by commercial relations and as illustrative of the mutual faith, confidence and respect each has for the other."

In addition to the statutory authority contained in Section 3 of the Natural Gas Act there is another source for the jurisdiction of the Federal Power Commission. This control of exports and imports is exercised in an indirect way through the issuance of so-called Presidential permits. Before any export or import of gas may be made, specific authority of the President of the United States is required. By an Executive order dated September 3, 1953, President Eisenhower delegated the authority of the issuance of such permits to the Federal Power Commission. Unfortunately, perhaps, no standards were transmitted to the Commission at that time by which the Executive Branch felt governed. Accordingly, the policy of the Commission has not been fixed. To date, the lack of such policy has not been important because of the limited exercise of the authority.

Now that large volume imports have become a distinct possibility, however, it has become imperative for the United States Government to establish some guideposts for the issuance of these permits. Since they are Presidential permits, presumably the standards could not be found in the Natural Gas Act. Accordingly, it is reasonable to expect that the Executive Branch of the Government will express some statement of policy in the foreseeable future with respect to the standards which can be expected to govern the issuance of these permits. Presumably, again, these standards would require the cooperation of agencies other than the Federal Power Commission since so many interests are involved. In any event, neither the lack of such standards now, nor the form they will take ultimately should be allowed to impede the cordial exchange of energy between the United States and Canada.

On the other hand, Canada too has its own statutory powers and responsibilities which it must observe. No opinion is expressed as to whether they need further amplification or modification. This question properly may be reserved to the internal responsibility of that nation.

In Canada the only authority so far vested in a Governmental Dominion Ministry is found in the Pipelines Act. Construction of a section of an interprovincial or international gas or oil pipe line may not be commenced without leave of the Board of Transport Commissioners for Canada. Applications for leave to construct pipe lines are usually set down for public hearing after notice to interested parties by mail and newspaper advertisement. Leave has been granted to construct such major pipe lines as the Trans-Canada natural gas line from Alberta to points in Ontario and Quebec; the Westcoast Transmission gas line from the Peace River areas to serve Vancouver and other points in British Columbia and markets in the United States. Major considerations in such applications are public interest, financial responsibility of the company and the economic feasibility of the project.

The Board may make regulations providing for the protection of property and the safety of the public and of the company's employees in the operation of pipe lines.

It may make orders and regulations with respect to all matters relating to traffic, tolls and tariffs of oil pipe lines, but it does not have similar powers over gas pipe lines.

The experience of the Canadian Government in authorizing exports of gas does not lend itself to analysis to determine policy. Moreover, the pending study being made by the Borden Commission will develop this subject at some length.

Through sources such as newspapers and trade journals it is noted that briefs have been filed to the Borden Energy Commission by the several interests interested in the problem. Some of them apparently have called for a national policy in Canada that will assure development of the gas industry serving Canadian consumers while at the same time providing for the exportation of the surplus gas. The New York Times on February 13 reports that the Canadian Petroleum Association has taken a position that gas exports from Canada could go a long way in stimulating investment capital to develop the vast reserves in western Canada.

Since it is reliably reported in the press of as recently as February 22 that the Borden Commission will definitely make an interim report on the problem of natural gas exports as soon as possible, it is reasonable to expect that a statement of opinion on this important matter is not far away.

Finally, the writers optimism derives from confidence that cordial and friendly relations between Canada and the United States will continue. This is the strongest indication and soundest basis for judgement that the ultimate conclusions on the policy of construction of international pipelines will coincide with the best interests of both Canada and the United States.

No comment is expressed on pending applications for specific export authority into the United States. Naturally, these are in the process of litigation before the Commission and any statement at this time is inappropriate.

Similarly, no comment on the possible outcome of any of the many issues which the Borden Commission necessarily must consider. Indeed, like the applications pending before the Conservation Boards of the several Provinces, the National and Provincial integrity is to be respected in this matter.

This discussion is directed entirely towards the long-range prospect of satisfactory solution of the problem of distributing the energy resources found in the far Pacific Northwest. It is felt that with this repeated hope and confidence that the solutions to these problems in the governmental and legal field will be as swift and sure and practical as the solutions in the engineering field which have been reached by men of that learned discipline.

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

CONTENTS

DISCUSSION
(Proc. Paper 1691)

HYDROSTATIC TESTING OF PIPE LINES[a]

Discussion by A. B. Wilder
Closure by Leon E. Brooks

A. B. WILDER.[1]—The author has presented a clear description of a method employed for hydrostatic testing of pipelines. Is information available regarding the number of gas pipelines being hydrostatically tested? In the manufacture of line pipe, hydrostatic testing is universally used. It would be unsafe to employ air for high pressure testing in the pipe mills unless extreme precautions were exercised to protect human life.

In the construction of pipelines, low ambient temperatures may prevent proof testing with water. Use of an anti-freeze at very low temperatures would be costly and therefore not practical. It should be noted, however, that the possibilities of a very long fracture are increased if a defective piece of pipe is encountered during gas testing at low temperatures. Pipelines which must be proof tested at low temperatures may be tested with gas and operated at a low pressure with circumferential stresses, possibly not exceeding 10,000 psi, and later hydrostatic tested so that the line may be operated at its design pressure.

In the hydrostatic testing of a pipeline, higher testing pressures than are required in the codes for gas testing may be used. This will provide a safer pipeline due to the elimination of additional defects if they are present. However, it would appear that the test pressure should not exceed the specified minimum yield strength in accordance with the specification for the material. There have been pipelines tested, as the author described, to the actual yield point of the material. This would mean that the lowest yield strength material would actually yield during testing of the line. Hydrostatic testing would be required in order to determine the yield strength during testing. It is our understanding that pipelines tested under these conditions, in the majority of cases, have been satisfactory in service. Hydrostatic testing is advantageous not only from safety aspects, but also because the break that may occur if a defect is encountered in the pipeline will be very short. However, if pipe expanded during hydrostatic testing beyond the yield strength without indicating yield, the material may indicate satisfactory service, but would be a potential source of failure at some future time due to the excessive expansion of the pipe.

Satisfactory public relations are maintained with hydrostatic testing of gas pipelines because explosions, for example, are not encountered and the possibilities of loss of human life are reduced to a minimum. Comments of the

a. Proc. Paper 1375, September, 1957, by Leon E. Brooks.
1. Chief Metallurgist, National Tube Div., U. S. Steel Corp.

author on the service performance of pipelines hydrostatically tested to the actual yield strength of the material will be of interest.

LEON E. BROOKS.[1]—The discussion has brought forward several points that should be clarified with regards to method, problems, and results of our present experience in hydrostatic testing. This experience is limited, due to the fact that high-pressure testing of gas pipelines in its finer points has been developed relatively recently, and its extensiveness is probably directly related to the change in the ASA Code which was adopted in 1951. At the present, practically every gas pipeline company has either done some hydrostatic testing or is considering such in the near future.

In testing lines where low ambient temperatures are encountered, this becomes a serious problem when the frost line is below the depth of the pipe cover. If the frost line is not that low, then the problem is limited to above ground valves and piping, which can be overcome either by tarps and heaters of some type, and/or after the line is filled, pressuring the line with an alcohol solution. This is all that is necessary to keep the manifolding near the pressure point, as well as the gauge connections and gauges from freezing. This is a minor expense.

The cleaning of the line is more difficult under these conditions because of the operating problems encountered while the dew point of the gas remains relatively high. It certainly would be advantageous to gas test and operate at a lower pressure, should the above conditions prohibit hydrostatic testing at the time of completion of the line.

In the selection of a maximum test pressure, a criteria is that the pipeline itself will not be damaged from the test except in defective pipe. If this pressure is a point of yielding, or just before reaching that point, then a yield curve probably should be plotted when approaching the specified minimum because secondary stresses that are present in the line can cause actual yielding to occur at pressures lower than the pressure based on the specified minimum. Lines that have been tested to yield strength have had excellent service records, and in most cases had failures in defective pipe during the test that would not have been eliminated during the test otherwise. Of course, that these were potential service failures is pure speculation. There have been no service failures that were in any way traceable to yield testing and, to the knowledge of the writer, no service failures in any new pipe line tested in this manner. However, the same holds true for lines tested to the specified minimum yield. Regarding the damage or increased chance of future failure caused by yielding the pipe in a test, it is felt that if present known techniques are used and precautionary steps taken during the test itself, the most important of which is a maximum pressure not to be exceeded under any circumstances, then the chance that excessive expansion will occur is remote.

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FLOW EQUATIONS FOR NATURAL GAS PIPELINES[a]

Discussion by James H. Dorough

JAMES H. DOROUGH.[1]—The paper is an excellent presentation of the flow formulae that have found widespread use within the gas transmission industry.

The comparison of the calculated results as to expected capacity is very valuable, especially with the appraisal of the Weymouth Equation which was used as a basis for comparison.

The author is well qualified to make these comments and the paper adds to the factual literature on the subject of flow equations.

The discusser does not fully concur with the views expressed by the author in subordinating the significance of absolute accuracy in the first and second applications. These applications as stated in the paper are (1) design of pipelines for capacity and (2) pipeline operations study.

The point was made that in these applications you are working with estimated loads which are usually subject to sizeable errors. While it is true that the estimate for future requirements is subject to error, once these estimates are made they become fixed quantities in the design or determination of capacity available for sale through existing facilities. The design engineer makes definite statements as to expenditures required for given increases in capacity or sales available from existing facilities and must be able to support his conclusions.

Based on these statements the capacity available is usually written as firm commitments in sales contracts. It, therefore, behooves the design engineer to select an equation which will result in the best possible accuracy regardless of the specific application.

The paper is characteristic of the present thinking within the high pressure transmission companies. They are guilty of seeking a solution to their particular problems and are forgetting the distribution companies where the flow rates are not as great for given pipe diameters operating at lower pressures. Lower rates of flow give corresponding lower Reynold's numbers.

Subsequent investigation of the flow test carried out on Southern Natural Gas Company's system would indicate that the Reynold's number does have a slight influence on flow characteristics even in the range of three to seven million for 16 and 18 inch pipe diameters. These tests are presented in Appendix A of the reference material, "Proceedings of the American Society of Civil Engineers Paper 1194 (1957).

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a. Proc. Paper 1667, June, 1958, by R. F. Bukacek.

1. Southern Natural Gas Co., Birmingham, Alabama.

Attention is called to test numbers 171 through 180. These tests were performed over the same sections of 16 and 18 inch pipe for varying flow conditions.

Test No.	Pipe Diameter	Flow Rate	Reynold's No.	Transmission Factor	Absolute Roughness from Colebrook Equation
179	16 inch	126,993 Mcfd	7,728,000	19.745	.000478
171	16 inch	120,668 Mcfd	7,232,000	19.585	.000531
174	16 inch	97,780 Mcfd	6,054,000	19.574	.000498
175	16 inch	71,539 Mcfd	4,440,000	19.309	.000538
178	16 inch	57,159 Mcfd	3,565,000	18.945	.000668
180	18 inch	142,800 Mcfd	7,721,000	20.024	.000425
172	18 inch	125,740 Mcfd	6,737,000	19.972	.000414
173	18 inch	101,610 Mcfd	5,498,000	19.909	.000385
176	18 inch	76,768 Mcfd	4,249,000	19.611	.000432
177	18 inch	57,653 Mcfd	3,199,000	18.709	.000880

The 18 inch pipe was installed seven years later than the 16 inch pipe which is apparent from the slight increase in absolute roughness. The Transmission Factor is also seen to increase with the increase in flow rates.

Test #178 and #177 are obviously out of line. A possible explanation for this variance could be explained in that the flow rate had been reduced to such extent that the pressure drop was only 8.5 Psi for test #177. The pressures were taken with dead weight gauges reading to the nearest one-tenth of a pound and possible error of as much as two-tenths would make quite a difference. The test section was approximately 16.56 miles in length.

While there is only a slight increase in the transmission factor and this fact is concurred with by many investigators, we should strive to give consideration to this change even in the transmission business and certainly for engineers use in the distribution companies.

With the present trend toward the use of high speed computers in design of pipelines, it no longer is desirable to sacrifice accuracy for simplicity. A method for considering this variation of transmission factor as a function of Reynold's number is presently under study here at Southern Natural Gas Company.

Considering the possible refinements to the flow equation, it is conceivable that once the absolute roughness of a section of pipe is determined by flow test then this section can be used for main line measurement in day to day dispatching and for efficiency checks of the entire gas transmission system.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1449 is identified as 1449 (HY 6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1957.

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JUNE: 1260(HY3), 1261(HY3), 1262(HY3), 1263(HY3), 1264(HY3), 1265(HY3), 1266(HY3), 1267(PO3), 1268 (PO3), 1269(SA3), 1270(SA3), 1271(SA3), 1272(SA3), 1273(SA3), 1274(SA3), 1275(SA3), 1276(SA3), 1277 (HY3), 1278(HY3), 1279(PL2), 1280(PL2), 1281(PL2), 1282(SA3), 1283(HY3)[c], 1284(PO3), 1285(PO3), 1286 (PO3), 1287(PO3)[c], 1288(SA3)[c].

JULY: 1289(SM3), 1290(EM3), 1291(EM3), 1292(EM3), 1293(EM3), 1294(HW3), 1295(HW3), 1296(HW3), 1297 (HW3), 1298(HW3), 1299(SM3), 1300(SM3), 1301(SM3), 1302(ST4), 1303(ST4), 1304(ST4), 1305(SU1), 1306 (SU1), 1307(SU1), 1308(ST4), 1309(SM3), 1310(SU1)[c], 1311(EM3)[c], 1312(ST4), 1313(ST4), 1314(ST4), 1315 (ST4), 1316(ST4), 1317(ST4), 1318(ST4), 1319(SM3)[c], 1320(ST4), 1321(ST4), 1322(EM3), 1323(AT1), 1324 (AT1), 1325(AT1), 1326(AT1), 1327(AT1), 1328(AT1)[c], 1329(ST4)[c].

AUGUST: 1330(HY4), 1331(HY4), 1332(HY4), 1333(SA4), 1334(SA4), 1335(SA4), 1336(SA4), 1337(SA4), 1338 (SA4), 1339(CO1), 1340(CO1), 1341(CO1), 1342(CO1), 1343(CO1), 1344(PO4), 1345(HY4), 1346(PO4)[c], 1347 (BD1), 1348(HY4)[c], 1349(SA4)[c] 1350(PO4), 1351(PO4).

SEPTEMBER: 1352(IR2), 1353(ST5), 1354(ST5), 1355(ST5), 1356(ST5), 1357(ST5), 1358(ST5), 1359(IR2), 1360 (IR2), 1361(ST5), 1362(IR2), 1363(IR2), 1364(IR2), 1365(WW3), 1366(WW3), 1367(WW3), 1368(WW3), 1369 (WW3), 1370(WW3), 1371(HW4), 1372(HW4), 1373(HW4), 1374(HW4), 1375(PL3), 1376(PL3), 1377(IR2)[c], 1378 (HW4)[c], 1379(IR2), 1380(HW4), 1381(WW3)[c], 1382(ST5)[c], 1383(PL3)[c], 1384(IR2), 1385(HW4), 1386(HW4).

OCTOBER: 1387(CP2), 1388(CP2), 1389(EM4), 1390(EM4), 1391(HY5), 1392(HY5), 1393(HY5), 1394(HY5), 1395 (HY5), 1396(PO5), 1397(PO5), 1398(PO5), 1399(EM4), 1400(SA5), 1401(HY5), 1402(HY5), 1403(HY5), 1404 (HY5), 1405(HY5), 1406(HY5), 1407(SA5), 1408(SA5), 1409(SA5), 1410(SA5), 1411(SA5), 1412(EM4), 1413 (EM4), 1414(PO5), 1415(EM4)[c], 1416(PO5)[c], 1417(HY5)[c], 1418(EM4), 1419(PO5), 1420(PO5), 1421(PO5), 1422(SA5)[c], 1423(SA5), 1424(EM4), 1425(CP2).

NOVEMBER: 1426(SM4), 1427(SM4), 1428(SM4), 1429(SM4), 1430(SM4)[c], 1431(ST6), 1432(ST6), 1433(ST6), 1434(ST6), 1435(ST6), 1436(ST6), 1437(ST6), 1438(SM4), 1439(SM4), 1440(ST6), 1441(ST6), 1442(ST6)[c], 1443(SU2), 1444(SU2), 1445(SU2), 1446(SU2), 1447(SU2), 1448(SU2)[c].

DECEMBER: 1449(HY6), 1450(HY6), 1451(HY6), 1452(HY6), 1453(HY6), 1454(HY6), 1455(HY6), 1456(HY6)[c], 1457(PO6), 1458(PO6), 1459(PO6), 1460(PO6)[c], 1461(SA6), 1462(SA6), 1463(SA6), 1464(SA6), 1465(SA6), 1466(SA6)[c], 1467(AT2), 1468(AT2), 1469(AT2), 1470(AT2), 1471(AT2), 1472(AT2), 1473(AT2), 1474(AT2), 1475(AT2), 1476(AT2), 1477(AT2), 1478(AT2), 1479(AT2), 1480(AT2), 1481(AT2), 1482(AT2), 1483(AT2), 1484(AT2), 1485(AT2)[c], 1486(BD2), 1487(BD2), 1488(PO6), 1489(PO6), 1490(BD2), 1491(BD2), 1492(HY6), 1493(BD2).

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JANUARY: 1494(EM1), 1495(EM1), 1496(EM1), 1497(IR1), 1498(IR1), 1499(IR1), 1500(IR1), 1501(IR1), 1502 (IR1), 1503(IR1), 1504(IR1), 1505(IR1), 1506(IR1), 1507(IR1), 1508(ST1), 1509(ST1), 1510(ST1), 1511(ST1), 1512(ST1), 1513(WW1), 1514(WW1), 1515(WW1), 1516(WW1), 1517(WW1), 1518(WW1), 1519(ST1), 1520 (EM1)[c], 1521(IR1)[c], 1522(ST1)[c], 1523(WW1)[c], 1524(HW1), 1525(HW1), 1526(HW1)[c], 1527(HW1).

FEBRUARY: 1528(HY1), 1529(PO1), 1530(HY1), 1531(HY1), 1532(HY1), 1533(SA1), 1534(SA1), 1535(SM1), 1536(SM1), 1537(SM1), 1538(PO1)[c], 1539(SA1), 1540(SA1), 1541(SA1), 1542(SA1), 1543(SA1), 1544(SM1), 1545(SM1), 1546(SM1), 1547(SM1), 1548(SM1), 1549(SM1), 1550(SM1), 1551(SM1), 1552(SM1), 1553(PO1), 1554(PO1), 1555(PO1), 1556(PO1), 1557(SA1)[c], 1558(HY1)[c], 1559(SM1)[c].

MARCH: 1560(ST2), 1561(ST2), 1562(ST2), 1563(ST2), 1564(ST2), 1565(ST2), 1566(ST2), 1567(ST2), 1568 (WW2), 1569(WW2), 1570(WW2), 1571(WW2), 1572(WW2), 1573(WW2), 1574(PL1), 1575(PL1), 1576(ST2)[c], 1577(PL1), 1578(PL1)[c], 1579(WW2)[c].

APRIL: 1580(EM2), 1581(EM2), 1582(HY2), 1583(HY2), 1584(HY2), 1585(HY2), 1586(HY2), 1587(HY2), 1588 (HY2), 1589(IR2), 1590(IR2), 1591(IR2), 1592(SA2), 1593(SU1), 1594(SU1), 1595(SU1), 1596(EM2), 1597(PO2), 1598(PO2), 1599(PO2), 1600(PO2), 1601(PO2), 1602(PO2), 1603(HY2), 1604(EM2), 1605(SU1)[c], 1606(SA2), 1607(SA2), 1608(SA2), 1609(SA2), 1610(SA2), 1611(SA2), 1612(SA2), 1613(SA2), 1614(SA2)[c], 1615(IR2)[c], 1616 (HY2)[c], 1617(SU1), 1618(PO2)[c], 1619(EM2)[c], 1620(CP1).

MAY: 1621(HW2), 1622(HW2), 1623(HW2), 1624(HW2), 1625(HW2), 1626(HW2), 1627(HW2), 1628(HW2), 1629 (ST3), 1630(ST3), 1631(ST3), 1632(ST3), 1633(ST3), 1634(ST3), 1635(ST3), 1636(ST3), 1637(ST3), 1638(ST3), 1639(WW3), 1640(WW3), 1641(WW3), 1642(WW3), 1643(WW3), 1644(WW3), 1645(SM2), 1646(SM2), 1647 (SM2), 1648(SM2), 1649(SM2), 1650(SM2), 1651(HW2), 1652(HW2)[c], 1653(WW3)[c], 1654(SM2), 1655(SM2), 1656(ST3)[c], 1657(SM2)[c].

JUNE: 1658(AT1), 1659(AT1), 1660(HY3), 1661(HY3), 1662(HY3), 1663(HY3), 1664(HY3), 1665(SA3), 1666 (PL2), 1667(PL2), 1668(PL2), 1669(AT1), 1670(PO3), 1671(PO3), 1672(PO3), 1673(PL2), 1674(PL2), 1675 (PO3), 1676(PO3), 1677(SA3), 1678(SA3), 1679(SA3), 1680(SA3), 1681(SA3), 1682(SA3), 1683(PO3), 1684 (HY3), 1685(SA3), 1686(SA3), 1687(PO3), 1688(SA3)[c], 1689(PO3)[c], 1690(HY3)[c], 1691(PL2)[c].

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c. Discussion of several papers, grouped by divisions.

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